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BULLETIN
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American Association *of* Petroleum Geologists

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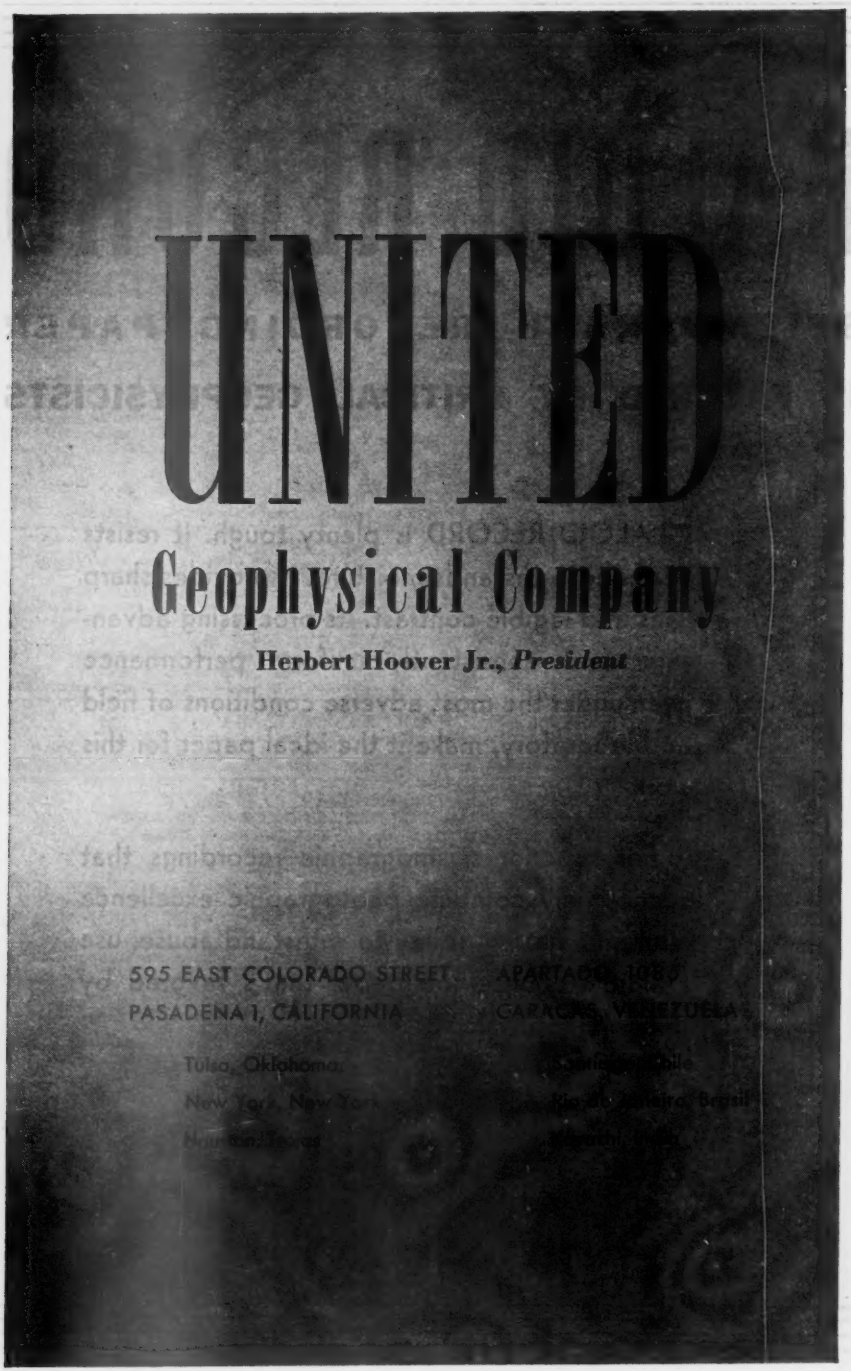
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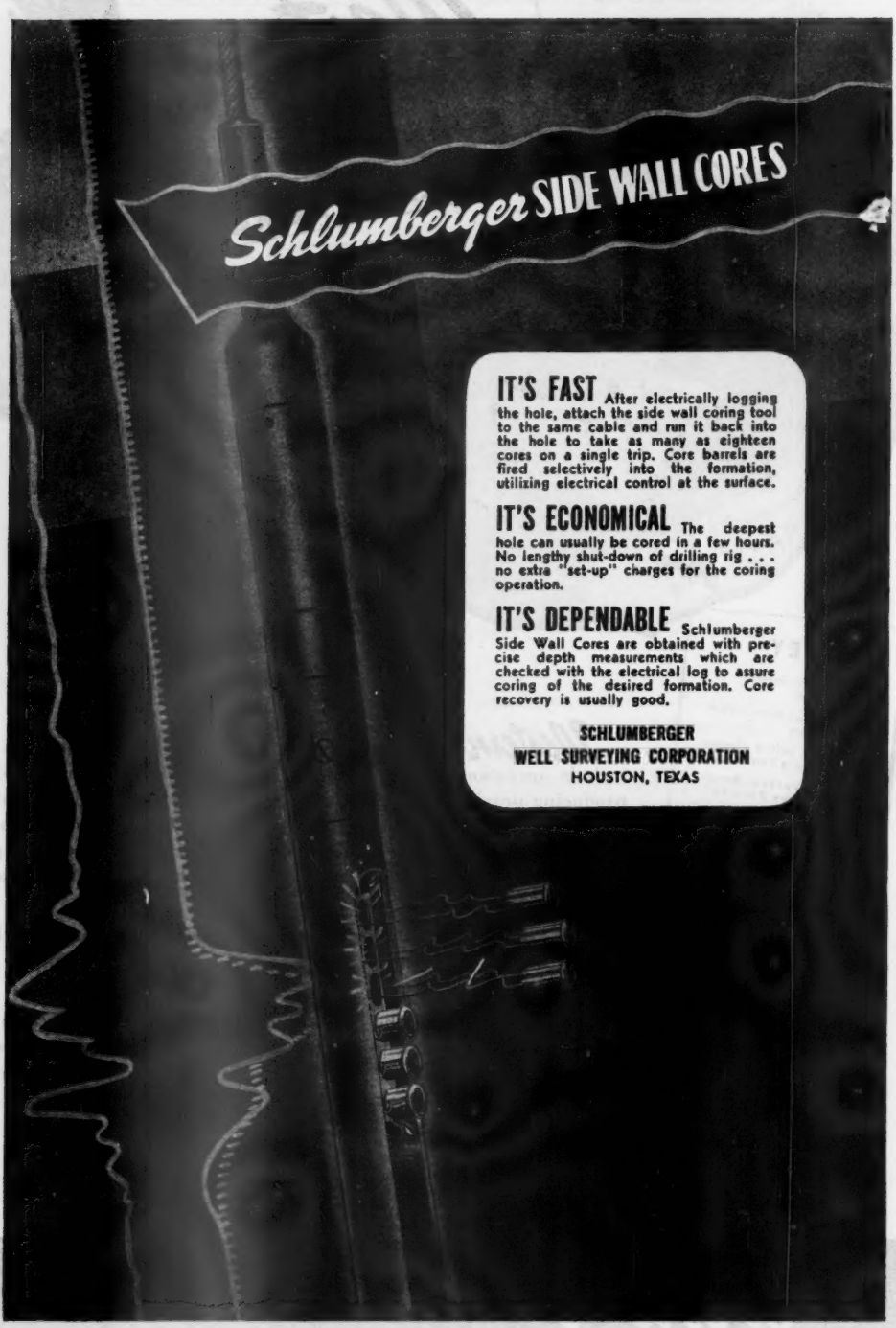
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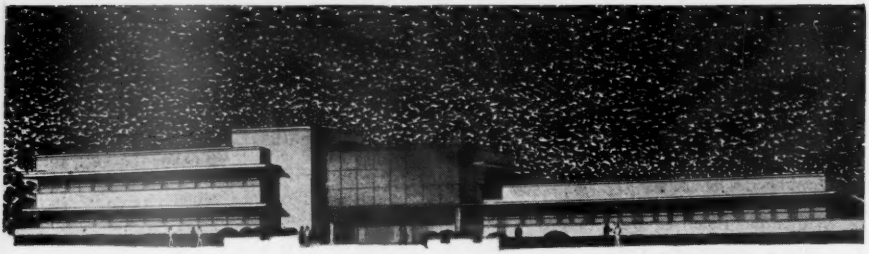

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BULLETIN
of the
AMERICAN ASSOCIATION OF
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FEBRUARY, 1948

PETROLEUM PROBLEM OF SIBERIA[1]

DIMITRY A. SHANAZAROV[2]
Buenos Aires, Argentina

PART I. GENERAL DESCRIPTION OF DEVELOPMENT OF EXPLORATION FOR OIL IN SIBERIA

Since the 17th century, gold has attracted to the bleak country of Siberia the attention of scientists, among whom may be mentioned the well known names of Gmelin, Gheorgi, and Pallas.

By the end of the 18th century, geological mining maps had been made of the regions with particular economic interest.

About 1850, the first geological map appeared.

In the period between 1851 and 1888, the Russian Academy of Science and several other scientific and military institutions organized mining, geological, paleontological, and many other expeditions which advanced into the most remote parts of this vast Russian Empire. Kamchatka and Sakhalin were reached on the Far East and the Altai Mountains of Southern Siberia were explored.

It was in this period of time that the first stratigraphical map of Siberia was made.

From 1889 to 1917 most detailed studies were concentrated in the gold-bearing regions, where exploitation increased on a large scale.

In spite of the mining and geological studies which lasted more than a century, Siberian petroleum possibilities were almost wholly neglected and only the gas deposits of the Lake Baikal aroused meager interest.

The problem of the petroleum possibilities of Siberia came up for discussion for the first time in 1929, when Professor A. D. Arkhanguelsky, a member of the Russian Academy of Science, attracted attention to the presence in this enormous territory of bituminous limestones and oil seepages related to these limestones.

Until 1931, however, the problem of the Siberian petroleum possibilities was

[1] Manuscript received, August 30, 1947.

[2] Geophysicist, mining engineer.

discussed only in the pages of scientific publications and the practical solution of the problem had not been attempted.

In the meantime the question of supplying Siberia with petroleum products, lubricants, and fuels, was becoming more and more acute.

The known petroleum occurrences, located nearest to Siberia, are those of Bashkiria in the west (from 1936), those of the Emba region in the southwest (from 1935, date of the completion of the Guriev Orsk pipe line) and those of Sakhalin Island in the east (from 1926). In the remainder of the entire territory which extends from the Ural Mountain chain to the Pacific coast, no commercially exploitable petroleum occurrences are as yet known.

On the other hand, the needs of the Siberian territory in liquid combustibles increase from day to day, especially if one takes into consideration the development of industry and of automotive transport, and the rapid increase of the number of agricultural tractors. According to recent estimates, the consumption of petroleum products in Siberia had reached 4,000,000 tons in 1941, and it was thought that it would increase to 6,000,000 tons during 1943. Because of the enormous distances in Siberia, the transportation of such a large quantity of petroleum and petroleum products requires the constant circulation of 30-35 special trains, constituting a very heavy burden for the Trans-Siberian Railway.

It is only natural that under such conditions the idea developed of supplying Siberia with petroleum products not only by improving transportation facilities, but also by producing liquid fuels within the limits of the Siberian territory itself.

Before authentic information had been obtained about the numerous occurrences of petroliferous rocks in Siberia, the attention of the responsible persons was concentrated especially on the exploration of various sapropelite and coal occurrences. The Siberian region is extremely rich in enormous coal deposits, and, what is particularly important, these deposits, though very different one from another in quality, as well as quantity, are nevertheless rather regularly distributed throughout the territory. Consequently, the distillation of these coals could have supplied substitute products for petroleum and its derivatives.

However, from the moment when the presence of numerous petroleum indications was proved in the Mesozoic, Devonian, and Cambrian rocks in Siberia, systematic explorations for oil occurrences were undertaken throughout this almost unlimited territory (this activity began in 1931, and, in the Lake Baikal region, even several years earlier).

The technical difficulties encountered in the course of petroleum explorations in the Volga Ural region were considerable; but the difficulties which were met with in Siberia were much greater. The extremely scattered locations of probable Siberian oil-bearing regions and the great distances which separate them from civilized centers and railway lines created almost insuperable obstacles. Almost everywhere extremely rigorous climatic conditions were experienced, and in many places the problem of drilling and of using petroleum in areas with permanently frozen ground had to be solved. Finally, the scarcity of accurate information regarding stratigraphic and structural details made it necessary not only to es-

tablish collaboration during the exploration work between representatives of all the various technical branches of the petroleum industry, but also to appeal to the collaboration of representatives of other scientific branches (geochemistry, geophysics, micropaleontology) in order to rationalize as much as possible this petroleum exploration work.

Until 1931, petroleum exploration in Siberia had been carried out exclusively in the region of Lake Baikal, where natural manifestations of gas, petroleum, and solid bitumens are known within a zone extending 250 kilometers along the eastern end of the lake. Sporadic exploration by means of shallow holes had been started already in 1902. However, the oil-bearing strata discovered before 1931 were not commercially exploitable.

Beginning with 1931, systematic research for petroleum was organized in all of the vast Siberian territory by utilizing the most modern methods of geology and geophysics, as well as microscopic and gasometric methods. All the exploration work is concentrated in the hands of the Institute for Geologic Exploration for Petroleum in Moscow. Drilling work in Siberia is at present still strictly exploratory; it is concentrated in the hands of a special administrative body, created in 1937, called "Siberia Petroleum Exploration."

The exploration carried out in Siberia before 1940 indicated the following regions (from west to east), which can be classified as probably oil-bearing.

Within the Ural region, in Western Siberia, strongly bituminous Mesozoic limestones were discovered in the basin of the Tavda River, in the vicinity of the town of Petropavlovsk. During the drilling of artesian water wells in this region numerous petroleum indications were observed.

Also in the southern part of Omsk City, the northern part of the Kazakhstan Republic, the borings made for the water investigations showed, at the depth of 921 meters, not only water but also petroleum traces. Besides, in this vast region between Omsk and Petropavlovsk many outcrops were found in addition to subsurface evidence in water wells, which showed liquid and solid bitumens and iridescent petroleum or emanations of combustible gas. All these oil-bearing manifestations appear to be related to Lower Cretaceous sediments. As the West Siberian basin, with exception of a narrow strip along its border, is covered by a thick succession of younger sediments, the petroliferous possibilities of this region could be determined only with the application of geophysical methods and deeper drilling. In 1941 numerous seismic, gravimetric, magnetic, and electric surveys were begun to determine the relief of the Paleozoic rocks. These geophysical surveys clearly established the accidental or unpredictable configuration of the Paleozoic bedrock. However, many favorable structures for the possible accumulation of petroleum were found. The mechanical problem of drilling in these latitudes, so far from lines of transportation and communication, represents the heaviest difficulties. Therefore, this drilling work should settle definitely the oil problem in this West Siberian basin, so important for developing the Ural metallurgical industry.

In the northern part of Western Siberia, the basin of the Yenisei River and

the basins of its affluents, the Sukhaia Tunguska and the Nijniaia Tunguska, may be considered as oil-bearing. The presence of carbonate rocks, containing liquid and solid hydrocarbons, has been determined over a vast area in this region. As the town of Turukhansk is situated in the vicinity of these probable oil-bearing regions, all this country has received the name of "oil-bearing region of Turukhansk." The age of the naphthogenic, sedimentary series extends from the Proterozoic to the Permo-Carboniferous. In this region the presence of three anticlinal structures with secondary petroleum indications in the form of plastic bitumens and pockets of asphalt has been determined. The area, where these favorable structures are situated, is outside the zone of permanently frozen ground; therefore the drilling of the first exploratory well was started in 1940 in the neighborhood of the town of Turukhansk. This well explored the oil-bearing Proterozoic rocks, which are at the surface here. Down to the depth of 600 meters no industrially exploitable oil-bearing beds were encountered—only traces of semi-liquid oil and pockets of asphalt. During 1941 drilling was begun to explore the younger naphthogenic rocks in the same region of Turukhansk, because of the great interest in the porous and cavernous Upper Silurian dolomites in which very strong indications of liquid and semi-liquid bitumens had been observed.

In the southern part of Western Siberia petroleum indications were discovered in the Kuznetzk and Minusinsk basins. The favorable geographic position of these two basins in the vicinity of the great Siberian communication lines stimulated detailed geologic explorations.

In the Kuznetzk basin, which as a whole is still insufficiently explored from the viewpoint of regional petroleum geology, plastic bitumens have been found in the northeastern part (in the region of Barsasa). These petroleum indications are connected with bituminous Devonian limestones, which extend over large areas in this region.

Similarly, in the Minusinsk basin, petroleum indications seem to be connected with Middle Devonian sediments, which are represented here by dark bituminous limestones, characterized by a strong petroleum smell. Also, very large asphalt deposits, extending over considerable areas, have been discovered in the Minusinsk basin. Geophysical exploration, begun in 1934 in the region of the Minusinsk basin, seems to have established the presence of salt domes of Devonian age. During 1940 drilling was begun on a rather large scale to check the conclusions of the geophysical exploration.

In the southern part of Western Siberia outcrops of oil-bearing rocks were found near the town of Nijne-Udinsk. In this area (in the valley of the Uda River) beds of an old oil-bearing sand were discovered in Lower Cambrian deposits, this sand having been altered to bituminous sandstone.

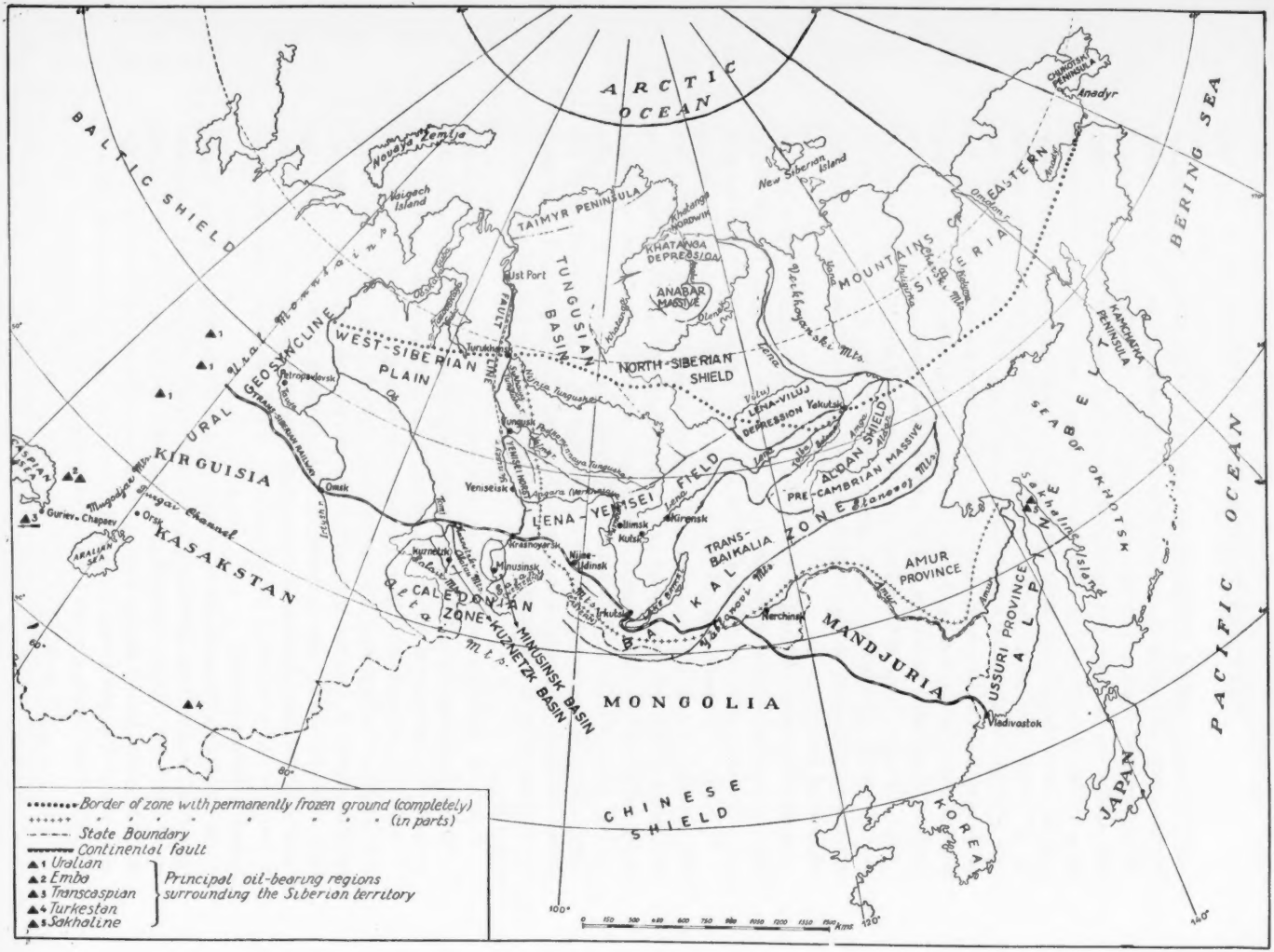
In Eastern Siberia, petroleum possibilities are known in the region of Lake Baikal and in the upper part of the basin of the Lena River (between the towns of Kirensk and Yakutsk).

In the region of Lake Baikal and the Angara River, important petroleum indications were discovered in the Cambrian sedimentary rocks. The presence of oil seepages and of emanations of combustible gases along the eastern borde of Lake Baikal, on the coast as well as in the lake itself, has been known for a long time. Systematic exploration was started in 1931, when all the methods of scientific research were applied for the first time: geology, geophysics (particularly the gasometric method), structure drilling, deep drilling, *et cetera*). The drilling work was done on the shore, as well as in the lake itself. For this purpose the long winter months have been used, during which the lake remains frozen, so that the derricks could be erected on the ice. To 1939 no petroleum deposits in commercially exploitable quantities had as yet been discovered in the region of Lake Baikal. However, such strong flows of combustible gases were found that at present special exploration is now going on to determine the possibilities of organizing independent exploitation of these gas accumulations for the neighboring town of Irkutsk.

Also in the upper part of the basin of the Lena River (and more particularly the basins of its southern affluents: Tolba, Botoma, and Amga), the petroleum indications are connected with sedimentary rocks of Cambrian age. Farther east of the Lena, in the basin of Yana River, traces of petroleum are known in Mesozoic sediments (Lower Cretaceous?). The exploration of this vast area offers very great difficulties, because all this country is covered by the "Taiga" (Siberian forest) and by marshes, and ways of communication are almost completely lacking. However, in 1938, favorable structure was indicated on the Tolba River. An exploratory well yielded a small flow of oil from the depth of 373 meters. However, it was too small to be of any practical importance. At present the exploration of the basin of the Lena River is being continued by mean of test wells.

Finally it must be mentioned, that in extreme northern Siberia, on the coast of the Arctic Ocean, certain indications of hydrocarbons have been recently discovered. Particularly numerous outcrops of oil-bearing formations were found in the estuary of the Yenisei River (Ust Port), in the region of the Bay of Narvik and the Bay of Kolesnikov. The New Siberian Island is not without oil-bearing manifestations. In fact the carbonate rocks of Paleozoic and Mesozoic age are here characterized by the presence of bituminous substances. However, the detailed exploration of these occurrences will become possible only if a solution is found to the problem of the exploitation of petroleum in regions with permanently frozen ground.

In conclusion, it can be stated that as regards Siberia the problem of liquid fuels has not yet been practically solved. In consideration of the conditions under which the exploration work is being carried out, it can be stated that the entire southern border of the Siberian platform, particularly the regions in the zone of the Trans-Siberian Railway between the towns of Krasnoyarsk and Irkutsk, offers certain chances for more or less immediate success.



MAP OF SIBERIA

The problem of liquid fuels in the Far East of the U.S.S.R. has already been favorably solved thanks to the rapid development of the oil industry on Sakhalin Island.

Part II. General Geology of Siberia

Principal subdivisions of Siberian territory

Before giving a description of the various Siberian oil-bearing regions and of the recent exploration work, it is necessary to deal briefly with the general outlines of the geological structure and of the geological history of Siberia. Thus, the purpose of this part of the article is not to give a comprehensive summary of the geology of Siberia, which may be found in many excellent, recently published works of Russian and foreign authors, but only to make the subsequent description of the Siberian oil occurrences more intelligible to the general reader, by presenting the most essential data regarding the petroleum geology of this country.

For this purpose the entire territory of Siberia may be subdivided into four parts.

Central Siberian platform

The Central Siberian Platform extends approximately from the Yenisei River in the west to the Lena River in the east. The northern boundary of this platform is formed by the shores of the Arctic Ocean and the southern boundary by the mountain chains, extending north of the present-day frontier between the U.S.S.R. and Mongolia.

In general, this is a country of a gently undulating relief, cut by the valleys of numerous rivers, some of which are among the longest in the world. Geologically this is a very ancient region, as it is composed mainly of Archean, Proteroz ic, and Lower Paleozoic rocks. More recent formations play a much less important part in the general structure of this region.

West Siberian plain

The West Siberian Plain extends from the Ural Mountain chain in the west to approximately the Yenisei River in the east, and from the Arctic Ocean in the north to the hills of the Kasakstan and to the South Siberian mountain chains in the south. With the exception of its western and southeastern border zones this is a uniformly flat plain, drained by the enormous system of the Ob River and of its affluents. The ancient, partly crystalline basement of Proterozoic and Lower Paleozoic rocks is located here at considerable depth and the entire basin has been filled by horizontal or gently undulated Upper Paleozoic, Secondary, and Tertiary deposits. The geological structure of this region, though probably rather simple and uniform, is greatly obscured by the presence of a rather thick cover of recent formations.

SOUTH SIBERIAN MOUNTAINS

The South Siberian Mountains extend as a very broad belt all along the southern border of the West Siberian Plain and of the Central Siberian Platform. This is a geosynclinal area, within which, in contrast to the Central Siberian Platform, mountain-forming processes have been particularly intense during almost every period of the history of the earth's crust. Therefore, the geological structure of this zone is extremely complex, deposits of almost every geological age taking part in its composition, these deposits having thereafter been greatly affected by the various epirogenic and orogenic cycles. At the present day this is a country of very complex mountain ranges, separated by rather deep basins, of which the Kuznetzk basin and the Minusinsk basin are of particular interest.

MOUNTAIN REGION OF EASTERN SIBERIA

The Mountain Region of Eastern Siberia extends from the course of the Lena River in the west to the shores of the Bering Sea in the east, and from the Arctic Ocean in the north to the Sea of Okhotsk in the south. This is a region of varied relief, inasmuch as long and very high mountain ranges (some of the summits exceeding 3,000 meters) alternate with faintly undulated table-lands and with broad valleys of mighty rivers, most of which flow into the Arctic Ocean.

From a stratigraphic standpoint, excepting for outcrops of a strongly folded, partly crystalline basement of Proterozoic and Paleozoic rocks, which come to the surface in some of the mountain ridges, this region is especially characterized by a considerable development of marine Mesozoic formations (Triassic and Jurassic, and partly Cretaceous), most of which have been affected by the Cimmerian orogenic movements. However, it must be mentioned that the study of the geologic and even of the topographic structure of this far distant zone is still at an early stage of development.

To this mountain region of Eastern Siberia must moreover be added the Amur province in the Russian Far East, extending between the southern part of the Stanovoj Mountain ridge and the Amur River.

We are not including in our description the relatively narrow, but very long belt of Alpine folds, extending all along the Pacific coast and embracing the Kamchatka Peninsula, the Island of Sakhalin, and the coastal line of the Ussuri province. Indeed, this coastal belt, in which Upper Tertiary and recent volcanic phenomena played and continue to play even at present a most important part, is so strongly differentiated from the bulk of the Siberian territory as regards general and petroleum geology, not to mention the radical differences in the purely economic aspects of the problems involved, that its description would be out of place in a study devoted essentially to the petroleum problems of the Siberian mainland.

While all of the aforementioned four main parts of the Siberian territory represent definite units and while each of them possesses some characteristics which differentiate it sharply from all the others, it must still be emphasized that

each of these units, far from being uniform, offers on the contrary, a very complex structure and consists of many different parts, as will be seen in the second part of this chapter, following a brief review of the geological history of Siberia, which will help in understanding the character of, and the reasons for, these more detailed subdivisions.

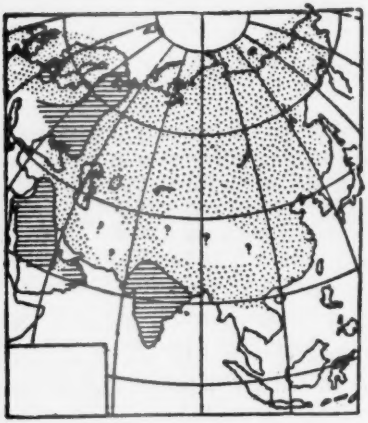
MAIN FEATURES OF GEOLOGICAL HISTORY OF SIBERIA

PRE-CAMBRIAN

The old controversy between two geological schools—the one represented mainly by Suess and Obrutshev, the other by De Launay, Borisjak, Shatski, and Arkhanguelski—as to whether the mountain ranges in the Baikal-Irkutsk region or the Central Siberian Platform, located north of them, is the fundamental and more ancient element of the geological structure of Siberia, has in fact no practical importance for the present purpose. Besides, it appears that it has already lost some of its acuteness, since recent authors, for example, K. Leuchs in his *Geology of Asia*, consider that the platform and the mountain range are in fact contemporaneous and that originally they formed one solid block or continent (the "Angara Land," according to Leuchs' terminology), consisting of strongly folded Archean formations. Be it as it may, it is now generally accepted that the basic part of the present Siberian territory is formed by the Central Siberian Platform, which is also sometimes called the Siberian Shield and is somewhat analogous with the Baltic Shield of European Russia and with the Canadian Shield. Already during Archean and Proterozoic time this platform or shield formed a large continent which, during subsequent geological periods, acted as a kind of bulwark, opposing its compact mass to the influence of all later mountain-forming forces.

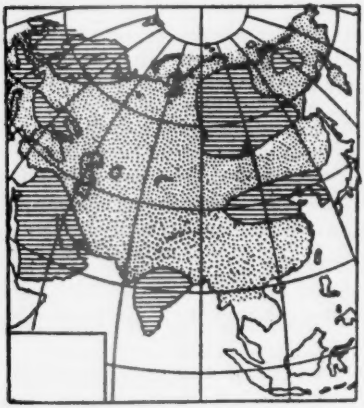
Thus, the solidity of this pre-Cambrian block explains why more recent folding processes are in general only poorly reflected, especially in the interior parts of this block, so that though the pre-Cambrian basement is strongly folded, the overlying Paleozoic and more recent formations are horizontal or are only gently undulated. On the contrary, in the border zones of "Angara Land," in the vicinity of more mobile, geosynclinal areas, folding phenomena could receive a more nearly complete development, and these folds have therefore the character of typical border folds, which, as seems to have been proved by recent investigations, surrounded the pre-Cambrian block, although at present they can easily be observed only in the south.

The foregoing considerations regarding the general solidity of the Archean Platform and the force of resistance offered by it, do not mean, however, that it always acted as one undivided block. On the contrary, its very lack of elasticity caused its disruption into a number of separate blocks, some of which were raised higher than the others, and it is only natural that in the higher blocks the force of resistance to the subsequent orogenic movements came to a greater expression than in the relatively depressed areas.

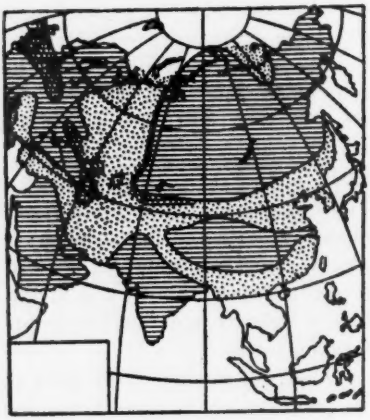


1. Middle Cambrian

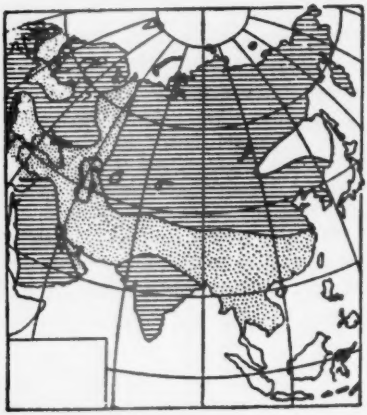
2. Upper Silurian



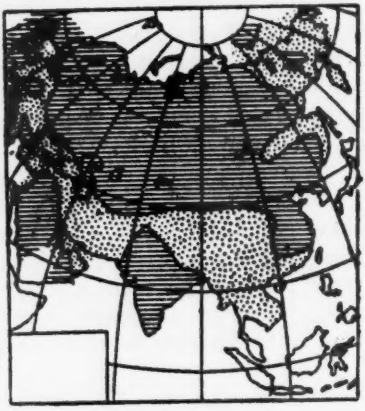
3. Upper Devonian



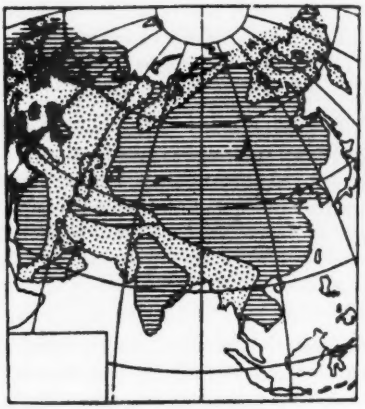
4. Middle Carboniferous



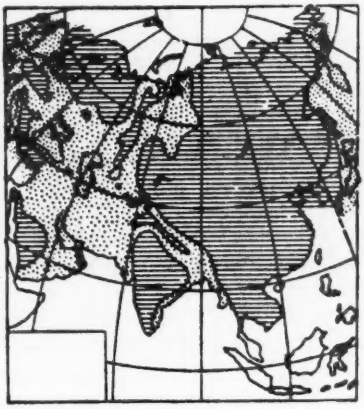
5. Upper Permian



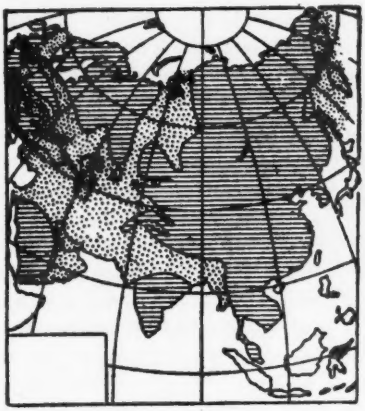
6. Upper Triassic



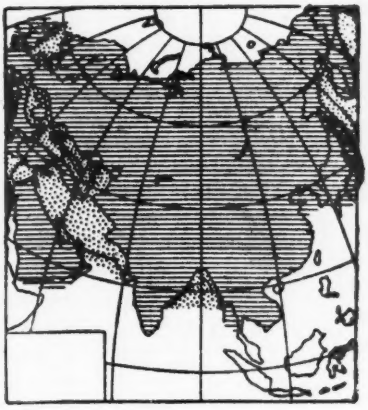
7. Upper Jurassic



8. Upper Cretaceous
Senonian



9. Upper Eogene



10. Middle Neogene

Eurasian Paleogeographic Maps

From A. D. Arkhanguelsky, "Structure et l'histoire géologique de U.S.S.R.," Volume II, pp. 301–322, *Rept. XVII Session International Geological Congress*, Petrograd and Moscow (1937)
Horizontal lines: Continental period
Dots: Sea
Horizontal lines and dots: Succession of sea and continental conditions

This Archean basement consists of strongly folded, partly metamorphosed rocks, such as crystalline shales, gneisses, and graphites, which crop out in large areas within the Siberian Platform and thus form several massives, among which the most important are the Anabar massive, situated along the Anabar River, and the Aldan massive, situated along a right-hand affluent of the Lena River, bearing the same name. Archean and Proterozoic rocks also crop out along the upper course of the Yenisei River, within the area of the so-called Yenisei horst, and they play a substantial part in the composition of the mountain chains, which border the Central Siberian Platform on the south (Eastern Sajany Mountain chain and Trans-Baikal Mountains).

CAMBRIAN PERIOD

A tremendous marine transgression took place during the Cambrian period, which affected almost all the older continental massives and reached its maximum during the middle of this period. In Asia the Cambrian transgression occupied an enormous territory and covered all of Siberia together with other parts of this continent. Thus this transgression affected equally the continental blocks (Central Siberian Platform) and the surrounding geosynclinal areas (West Siberian Plain, South Siberian Mountains, and Eastern Siberia). Cambrian deposits extend as a very broad belt throughout Eastern Siberia, across the basin of the Lena River and its affluents, and penetrate into Western Siberia, where they are, however, hidden by more recent formations. The thickness of the Cambrian deposits increases from the central parts of the Siberian Shield toward its borders. Within the areas of the old crystalline massives of Anabar and Aldan the Cambrian deposits are either completely absent or relatively thin, but their thickness increases considerably in the aforementioned depressed areas of the Central Siberian Platform, and it becomes still greater along its borders and in the geosynclinal areas.

Within the Anabar and the Aldan massives, the Cambrian deposits are almost horizontal on the strongly folded Archean basement. West and south of the Aldan massive, Cambrian deposits rest on Proterozoic formations, and not directly on the Archean basement, and they are considerably dislocated. This indicates that final folding of these rocks occurred during the later part of the Lower Paleozoic. Between the Eastern Sajany Mountain range and the upper course of the Lena River there is a broad belt of Cambrian deposits, folded into very large structures. These outcrops of the Proterozoic and Lower Paleozoic basement are surrounded by depression areas (such as the Khatanga and Viluj depressions; also the West Siberian Plain), where the folded basement lies at considerable depth. The depression areas are filled by horizontal or only slightly dislocated Upper Paleozoic or Mesozoic formations.

Lithologically, the Cambrian deposits, while naturally possessing distinct characteristics of a marine facies, offer all possible varieties, ranging from shoreline conglomerates to deep-water limestones with tribolites. It should be em-

phasized that Cambrian bituminous limestones, shales, and dolomites are particularly well developed and that they occupy vast areas in parts of Siberia.

From the tectonic standpoint, the Cambrian period was extremely calm and no mountain-forming or folding processes of any importance took place during this period within the Siberian territory.

SILURIAN PERIOD

All that has been said about the Cambrian period also applies to the lower part of the Silurian period. However, during the second part of the Silurian a gradual change set in. Upward epeirogenic movements manifested themselves first of all in the geosynclinal areas, namely, in the Ural geosyncline, which separated the Central Siberian Platform from the Baltic Shield, and in the North Asiatic geosyncline, which separated the Central Siberian Platform from the Chinese Shield. Deep-water deposits were gradually replaced in these geosynclinal areas by shallow-water formations. At first this regression in the geosynclinal areas caused an increase of transgression in the neighboring epicontinental areas (the sea which covered the Siberian Shield), but at the end of the Silurian period the rising movement of the earth's crust began to affect also the continental massive of the Central Siberian Platform, so that the Silurian basin within parts of this platform became lagoonal (dolomites, gypsiferous and salt-bearing beds). In the interior parts of the Central Siberian Platform the Silurian deposits were in general almost horizontal, whereas in the border zones they were intensely dislocated. Mountain-forming processes manifested themselves at places toward the very end of the Silurian period, all of which is in fact a forerunner of the big movements which reached their maximum during the next geological period (Caledonian cycle).

DEVONIAN PERIOD

The initial phases of the Devonian period are characterized by a general upward movement and a corresponding regression of the sea, as a result of which almost the entire territory of present-day Siberia remained above sea-level during this period with the exception of a long but relatively narrow stretch of territory coinciding more or less with the inner part of the Ural geosyncline, which separated the Siberian mainland from the Russian Platform. This upward movement was also accompanied by fairly intense folding processes, which affected particularly the Cambro-Silurian deposits in the region of the West Siberian Plain and in the South and East Siberian mountain regions, and, to a lesser degree, the same deposits in the depressed areas within the Central Siberian Platform, which are located between and around the ancient shields. Thus it was during the Upper Silurian and Lower Devonian periods (Caledonian cycle) that the pre-Cambrian and Cambro-Silurian formations within the West Siberian Plain were folded for the last time and received in this way their final shape. These ancient folded formations are at present at the surface along the borders of this plain, for ex-

ample, in the Ural Mountain chain, on Vaigach Island, on Novaja Zemlja, in the central parts of the Kasakstan and in the Altai Mountains. When, during later geological periods the territory of the West Siberian Plain again receded and was consequently flooded by subsequent marine transgressions (for the first time, during the Upper Devonian), these ancient folded Proterozoic and Cambro-Silurian formations formed a partly metamorphosed basement on which more recent formations were deposited almost horizontally.

It is to be noted that very large parts of the Central Siberian Platform never again receded under the sea and constantly remained a continental mainland during all subsequent geological periods. On the contrary, the geosynclinal areas were again covered by marine transgression by the end of the Lower Devonian.

Within the Ural Mountain chain, Devonian deposits extend along both its slopes from Novaja Zemlja in the north to the southern part of the Mugodiar Mountains in the south. Within the basin of the North Asiatic geosyncline, and especially within its western part, in the Minusinski and Kuznetzki region, deposits of the Devonian sea may be observed over distances of several hundred kilometers: in the lower parts they consist of clays, and in the higher parts they go over into limestones (commonly bituminous) with *Spirifer anossofi*, covered by sandstones and marls, with gypsum, salt, and vegetable remains. These deposits take part in the building-up of the mountain chains bordering the Siberian Shield on the southwest. In the Altai Mountains these Devonian deposits play the most important part among all sedimentary formations, and they can also be observed in the Kirguizian Mountain platform. In the east the Devonian deposits, represented by metamorphosed shales and quartzites, surround the southeastern part of the Central Siberian Platform and extend within the Amur basin and all along the shores of the Sea of Okhotsk.

CARBONIFEROUS PERIOD

After the temporary and incomplete transgression which took place during the Upper Devonian epoch, a new period of general regression of the sea set in with the beginning of the Carboniferous age. All of the Central Siberian Platform and practically all of Eastern Siberia remained above sea-level during the Carboniferous period and the extent of this continental massive was much larger than during the preceding Devonian. The extent of the Carboniferous sea was practically limited to the two large geosynclinal areas: the Ural geosyncline and the North Asiatic geosyncline, but even within these geosynclinal areas the marine transgression was not constant and not very strong. As a result, the sea was divided into a number of separate basins; consequently, shallow-water, shore, and lagoonal deposits, as well as continental formations, were typical for the Carboniferous period, particularly for its second part.

This period coincided with the beginning of the second orogenic phase of the Paleozoic age, known as the Hercynian cycle, which continued almost to the end

of the Permian period. Vigorous mountain-forming processes brought about an extension of the continental massives and a corresponding narrowing of the geosynclinal areas, which resulted in a larger development of continental deposits than had been the case during any of the preceding geological epochs. The Hercynian movements affected particularly the mountain chains of Southern Siberia, located between the Central Siberian Platform and the Tertiary (Alpine) mountain chains of the Altaides.

Carboniferous deposits are developed in the Kirguisian steppes, in the Russian Altai Mountains, but especially in the two celebrated coal basins of Kuznetzk and Minusinsk, where the Upper Carboniferous deposits are characterized by a typical continental facies and where they reach a very great thickness of more than 6,000 meters. Other Carboniferous formations have been observed in Transbaikal, as well as in the Amur regions of Eastern Siberia.

PERMIAN PERIOD

In general, it is very difficult to make a sharp distinction between Upper Carboniferous and Permian formations in Siberia, not only because this problem has not been sufficiently studied, but also because of the great similarity of the Upper Carboniferous and of the Permian fauna, and because the Permian formations in Siberia belong almost without exception to a continental facies. The geotectonic processes, which were described as being characteristic for the Carboniferous period were further intensified during the following geological age. As a result, the sea receded almost completely from the territory at present occupied by Siberia. At the beginning of the Permian period the sea was still present in the Ural geosyncline, in the Far East, and, though to a much smaller degree, in the North Asiatic geosynclinal area. However, in the second part of the Permian period Eastern Siberia emerged completely from the sea, the Uralian geosyncline was reduced to a very narrow stretch of territory, and the North Asiatic geosyncline was completely closed. In fact, it can not be any longer considered as a geosynclinal area: it was solidly added to the Central Siberian Platform and, together with the West Siberian Plain, it formed from that time onward one compact continental massive, the enlarged "Angara Land."

Continental and partly also lagoonal deposits predominated over marine sediments during the Permian period in Siberia. It is especially interesting to note that no marine Permian formations of any importance are known along the eastern slopes of the Ural Mountains, though they play an important part in the geological structure of the eastern half of European Russia. This is due to the fact that the rising of the Ural Mountain chain, caused by the Hercynian movements, opposed a barrier to the extension of the Permian sea toward the east. Marine Permian deposits were observed only in the Far East, where remnants of the epicontinental sea of Eastern Asia, represented by limestones with Brachiopoda, were found in the Ussuri region. On the contrary, continental Permian

formations extended very widely in Siberia, especially in the Kirguisian steppes, and in the basins of Kuznetzk and Minusinsk, as well as in the Tungusian basin (right bank of the Yenisei River).

TRIASSIC PERIOD

During the Triassic period several marine transgressions (at least two) occurred in Eastern Siberia. It seems that the sea extended from the Arctic Ocean and formed a large bay, pointed toward the south, so that it occupied the basins of the rivers Yana, Indiguirka, and Kolyma, extended from there into the southern part of the Sea of Okhotsk, and crossed the present-day Amur province. Recent investigations make it appear probable that this bay was in fact a channel, which through its southern extremity had at least a temporary communication with the Pacific. In northeastern Siberia the Triassic sea never extended beyond the course of the Lena River, whereas around the southeastern border of the ancient Angara Land it penetrated westward as far as the region of Nerchinsk.

Marine Triassic deposits have correspondingly been observed at various places in Eastern Siberia, where they reach a considerable thickness. They are particularly important in the western part of northeastern Siberia, where, according to recent investigations, they fill a geosynclinal area, located between two Proterozoic and Paleozoic border zones, represented by the Verkhojanski Mountain ridge and the outer parts of the Chersky ridge. In the eastern part of this geosynclinal area the Triassic deposits lie undisturbed but in the western part they have been intensely folded and greatly affected by granite intrusions, which accompanied the Cimmerian orogenic cycle. In the region of Nerchinsk, in eastern Transbaikal, marine Triassic deposits, represented by dark clayey or sandy shales with sandstones and conglomerates, also reached a considerable thickness.

On the other hand, outcrops of marine Triassic deposits are developed, though on a much smaller scale, in southwestern Siberia, along the very upper course of the Yenisei River. According to the opinion of A. Borisiak these Lower Triassic formations are remnants of a shallow epicontinental sea, which at that time formed an eastern extension of the Thetis.

All the remainder of the Siberian territory remained above sea-level during the Triassic, so that only continental formations represent this period within the greater part of Central and Western Siberia. It is assumed that the lower part of the continental Angara series, which has a very wide extent in various parts of the Siberian territory, belongs to the Triassic period. However, it should be noted that these continental Triassic deposits can not be very well differentiated from the equally continental Jurassic deposits, which form the main part of the Angara series.

JURASSIC PERIOD

During the Jurassic period the subdivisions between continental and marine areas remained almost the same as during the Triassic period; however, the ex-

tent of the Jurassic transgression is somewhat larger. Indeed, in addition to Eastern Siberia, the Jurassic sea covered also the shores of the Arctic Ocean, extending westward as far as the estuary of the Ob River. Within the eastern part of Central Siberia the Jurassic sea formed a westward-pointed bay, penetrating as far as the basin of the Viluj River, thus flooding the depressed area separating the Anabar shield from the Aldan block. The Khatanga depression of the Central Siberian Platform, situated north of the Anabar massive, was equally covered by the Jurassic sea. In the Amur, Ussuri, Mandjuria, and eastern Transbaikal regions the Jurassic transgression also occupied a larger territory than during the Triassic; however, this applies only to the Lower and Middle Jurassic periods, because during the Upper Jurassic the sea completely disappeared from the Amur and other provinces of the Russian Far East and also regressed beyond the middle course of the Lena River. On the contrary, in Northwest Siberia the Upper Jurassic transgression extended along the upper course of the Ob River and along the eastern slopes of the Ural Mountains (in their northern part), embracing also all the area of the Obskaya and Tazovskaya Guba and of the lower course of the Yenisei River.

But, though the Jurassic sea had an over-all larger extent than the Triassic sea, it was much less constant, so that this sea did not have the characteristics of a lasting transgression, but rather those of several short ingressions, interrupted by equally short regression periods. This is proved by the fact that almost everywhere, with the only exception of some areas along the shores of the Arctic Ocean, marine Jurassic deposits alternate with continental formations. The presence of numerous and abundant plant remains in many of the marine Jurassic deposits and their lithologic composition (in most places alternation of sands, sandstones, and very coarse conglomerates with sandy shales, and a complete absence of limestones) also confirms the vicinity of the shore lines in most of the Jurassic deposits in Eastern and Northern Siberia, which have been studied.

Continental deposits reached a very wide extent and a considerable thickness in many parts of the Siberian territory during the Jurassic period, but they are particularly noteworthy in its southern half, as in the basins of Kuznetzk and Irkutsk and in Transbaikal. As already mentioned, these continental Jurassic deposits form the main part of the so-called Angara series, under which name the Russian geologists usually group all the continental deposits of the Mesozoic age, which covered wide areas in that larger part of the Siberian territory which remained constantly above sea-level during the Secondary age.

CRETACEOUS PERIOD

In general, the Cretaceous period is characterized by strong movements in the geosynclinal areas and correspondingly large transgressions of the epicontinental seas; in Siberia, on the contrary, the area occupied by the sea was reduced to a minimum, probably because no important geosynclinal areas existed at that

time within the Siberian territory, even the Far Eastern geosynclinal having been partly closed by the Cimmerian orogenesis.

During the Lower Cretaceous the sea receded entirely from the Far East and from a part of the Arctic region, remaining there principally as a long and rather narrow bay in the region of the lower course and of the estuary of the Ob River. Farther west a narrow connection is supposed to have existed during the Aptian period between the Arctic Ocean and the eastern part of the Tethys. Later, the Cenomanian sea flooded the Kamchatka Peninsula and the Anadyr basin in the extreme northeastern part of Siberia, as well as Sakhalin Island, but at the same time the sea receded from the Ob region and the communication between the Arctic Ocean and the Tethys was, at least temporarily, interrupted. Still later, during the Senonian period, a fairly important transgression took place in the western part of the West Siberian Plain. This Senonian sea was connected by means of two channels with the eastern extension of the Mediterranean, which at that time covered all of the southern part of European Russia, as well as the Aralo-Caspian region.

All the remainder of the Siberian territory was mainland during the Cretaceous and formed a part of the enormous Sino-Siberian continent.

The general characteristics of the Cretaceous sediments within the areas described are almost the same as those of the corresponding Jurassic deposits: an alternation of marine and continental deposits with a prevalence of littoral formations. Such Cretaceous formations have been observed along the eastern slopes of the Ural Mountains, in the estuary regions of the rivers Ob, Yenisei, Lena, and Yana, but especially in the Anadyr basin, where they reach a thickness of more than 4,000 meters and are represented essentially by sandstones with plant remains and fish teeth. Although continental Cretaceous deposits have probably a very wide extent in various parts of Siberia, their differentiation from other continental Mesozoic deposits is made very difficult because of almost complete absence of fossils. Probably they form the uppermost part of the Angara beds.

In order to complete this very brief review of the Mesozoic age, we must add a few words about the Cimmerian orogenesis, which in Siberia, and particularly in its eastern regions, played perhaps a more important part than anywhere else. This orogenic phase, which is in general considered as a forerunner of the Cenozoic Alpine movements, starts by the end of the Triassic period and revives again with particular force during the transition from the Jurassic to the Cretaceous. Recent researches have shown that the area within the influence of the Cimmerian orogenesis was much larger than previously supposed and that it included practically all of Siberia; on the other hand, it appears that these movements manifested themselves in very different manners in the various parts of this territory. We have already seen that during the Triassic period a regular geosynclinal area was formed which extended along the Verkhojansky Mountain ridge, that is, it bordered the old Angara Land or Central Siberian Platform from

the east. It is assumed that the eastern edge of this geosynclinal was formed by another ancient shield area, the so-called Tchukotski massive, remnants of which can be observed in the Tchukotski Peninsula and in some of the North Siberian islands. Within this mobile geosynclinal area the Triassic formations (and partly also the Jurassic formations during the Upper Cimmerian phase) formed folds of a distinctly Alpine type. On the contrary, within the southern border land of the Central Siberian Platform (especially in the Sajano-Transbaikal region), no such Alpine folds could be formed, because of the absence of any mobile zone and the great resistance offered by the old Paleozoic formations, which had been so strongly consolidated during the Caledonian and Hercynian orogenic phases. Therefore, the Cimmerian orogenesis manifested itself in this region principally by dislocations of the Germanic type: by faults, overthrusts, *charriage* phenomena, *et cetera*, which greatly obscure the original Caledonian and Hercynian structures. This also applies to the western border of Angara Land, and can be observed in parts of the eastern slopes of the Ural Mountains. Finally, as could be expected, the Cimmerian movements were felt much less in the interior parts of the Central Siberian Platform than along its border zones; indeed, in the uplifted shields or massives no Cimmerian folding took place at all, though in the depressed blocks, and particularly in the Viluj depression, where, the Triassic and Jurassic deposits are of particular importance, these deposits have been folded into a series of broad and gentle structures within the general framework of the Paleozoic basement.

TERTIARY PERIOD

Marine Tertiary deposits play a minor part in the general geological structure of Siberia. During the Paleogene a fairly large part of Western Siberia, extending from the eastern slopes of the Ural Mountains into the basins of the Ob and Irtysh rivers, was covered by an epicontinental sea, which communicated in the south, through the Turgai channel, with the Mediterranean basin. In the extreme east the sea covered the Anadyr basin, the Kamchatka Peninsula and Sakhalin Island. The greater (central) part of the Arctic region was mainland throughout the Tertiary, contrary to conditions during most periods of the Mesozoic.

During the Neogene a general regression occurred: in the West Siberian basin the sea retired first from the Turgai channel, interrupting the communication with the Mediterranean, and thereafter also from the northern areas. Almost the same happened in the extreme east, although during the Pliocene the sea again flooded Sakhalin Island and deposited the productive oil-bearing series, which has been exploited successfully during the last 25 years. Continental Tertiary deposits are developed in various parts of the Siberian mainland, but according to the present state of investigations they do not cover very wide areas; neither does it seem that they reach a considerable thickness.

During the Quaternary period very large marine transgressions took place, coming from the north, so that practically all the northern part of the West

Siberian Plain was hidden under a widely spread cover of marine Quaternary deposits, whereas in its southern part the deeper structure of the underlying formations is equally obscured by continental formations of the same age.

As regards tectonic phenomena, we have already seen that the Cimmerian orogenesis brought about an increase in territory and a further consolidation of the old Angara Land. In view of this, during the Tertiary period regular Alpine folding processes occurred only in the narrow stretch of territory all along the shores of the Pacific. The structure of this Alpine zone, some mountain ranges of which reached a considerable height especially in the Kamchatka Peninsula, is, however, greatly obscured by contemporary and even Quaternary volcanic activity. Outside this narrow zone the Alpine orogenesis manifested itself essentially by movements of the Germanic type, that is, by ruptures, faults, and other dislocations. Apart from orogenic movements, epeirogenic phenomena took place during the entire Tertiary and Quaternary, bringing about the sinking of some blocks of the Siberian territory and the raising of others. According to recent observations these epeirogenic movements are continuing even at present.

Part III. Possible Oil-Bearing Regions of Siberia

General Considerations

From the foregoing brief summary of the geological history of Siberia some general conclusions may be drawn, which have practical bearing on the problems of the regional petroleum geology in this vast territory, and in this way an attempt may be made to give a first general answer to the question as to where and under what conditions one has to look for petroleum in Siberia. This answer must necessarily take the form of a classification of the various parts of the Siberian territory considered from the viewpoint of the greater or smaller degree of probability of the presence of commercially exploitable petroleum reserves in these various parts. Thus, during the present preliminary stages of exploration, the negative task of eliminating unpromising territories is probably just as important for the final results, as the search for, and study of, actual petroleum occurrences in the form of surface indications *et cetera*.

In the first place we must mention the enormous prevalence of old deposits over the relatively younger ones. Marine Tertiary deposits, which yield all of the Caucasian crude, as well as that of the Ferghana province, that is, until very recently more than 80 per cent of the total Russian crude production, are of any importance in Siberia only in the extreme east, where the petroleum problem has already been solved in part since the discovery of large petroleum reserves in the Pliocene formations of Northern Sakhalin. It seems that as exploration for petroleum extends from the original Caucasian area and gradually embraces larger territories within the European and Asiatic parts of the U.S.S.R., the age of the promising and exploitable oil-bearing formations grows steadily older. As is generally known, in the Emba region the oil comes from Cretaceous and, to a

large extent, also from Jurassic deposits. In the new Ural-Volga region, the regular exploitation of which on a large scale started only about 10 years ago, the most prolific zones of the Artinsky stage are located in the Lower Permian, and in the northern part of the Russian Platform even Devonian formations seem to offer certain practical possibilities. In Siberia, it appears that the greatest interest is attached to Lower Paleozoic (Cambro-Silurian) deposits. Thus for the time being, the problem of Siberian oil is largely reduced to the study and exploration of Lower Paleozoic (chiefly Cambro-Silurian) deposits. This is due in the first place to the great extent of these formations almost throughout Siberia, but since they are particularly prevalent within the Central Siberian Platform, it is only natural that this platform is now considered as the first, the most serious, and also the most promising object to be tackled by Soviet geologists. In the second place, the lithologic composition of the Lower Paleozoic, and especially of the Lower Cambrian deposits, appears to be favorable for the formation of primary oil. In fact, the explorations of the last 10–12 years have shown in the most various places of the platform, but especially within its inner border zones, the presence of important deposits of dark bituminous shales, limestones, and dolomites, extending over large areas and having in general a very uniform character. The fact that these primary petroleum indications are especially numerous in the broad inner border zones of the platform can probably be explained by the particularly favorable conditions for the accumulation of organic material, which prevailed in these zones during the Lower Cambrian period, the sea not being too shallow as in the immediate vicinity of the borders, or above the uplifted crystalline massives, and yet not too deep as it seems to have been in some of the depressed areas. Formations which could play the part of reservoir beds were found in sufficient number not only in the Lower Cambrian deposits in the form of porous dolomites, but also in various zones of the Middle and Upper Cambrian and in the Silurian deposits (partly, but naturally to a much smaller extent, also in Upper Paleozoic and Mesozoic deposits). Finally, it is very important to note that the general distribution of favorable and unfavorable tectonic zones within the Central Siberian Platform more or less coincides with that of the lithologic zones. Indeed, though immediately along the borders of the platform the Cambrian formations appear to have been very strongly dislocated, and though above the crystalline massives and probably also within the strongly depressed areas, they are almost horizontal, in the inner border zones they seem to have been frequently folded into large structures with gently dipping flanks. A fairly large number of such favorable structures, built up by Cambrian formations, have been discovered during the last few years.

The lower Proterozoic formations have also recently attracted the attention of Russian geologists, but, though final judgment can not yet be formulated and though probably the solutions will vary according to regional peculiarities, it seems that in a general way the rocks of the Proterozoic basement have been

metamorphosed to a great extent and have been strongly compressed into isoclinical folds, so that the possibilities offered by them appear to be rather small.

Marine Devonian deposits are much less developed in Siberia than the Cambro-Silurian rocks. For the moment it seems that from a practical standpoint they offer particular interest only in the two large coal basins of the South Siberian mountains: the Kuznetzki and the Minusinski basins.

Finally, it is evident that the study of the Upper Paleozoic (Permo-Carboniferous) and Mesozoic deposits should not be neglected, but we have already seen that their extent is much more limited than that of the Lower Paleozoic rocks, and in most places they are represented by continental formations which are of no interest from the point of view of petroleum geology.

The aforenoted prevalence of the Lower Paleozoic rocks and the greater possibilities probably offered by them, naturally puts before the local geologists entirely new problems and increases the difficulty of their task in a country, where exploration for petroleum is extremely difficult because of unfavorable geographical and economic conditions.

Keeping in mind these general remarks, we are now in a position to give a somewhat more detailed description of the principal geological regions of Siberia, subdivided into smaller units and considered from the viewpoint of their petroleum possibilities.

CENTRAL SIBERIAN PLATFORM

NORTH SIBERIAN SHIELD (INCLUDING ANABAR MASSIVE)

The north-central part of the Central Siberian Platform is occupied by the North Siberian Shield. This shield (which incidentally has also the form of one) extends west of the lower course of the Lena River and occupies the upper and middle parts of the basins of the Olenek, Anabar, and Khatanga rivers in the north, and the upper part of the basin of the Viluj River in the south. The central part of this enormous territory, which is about 1,200 kilometers in length and about 1,000 kilometers in width (in its northern broader part), is occupied by the so-called Anabar massive, which is considered by many geologists as structure of northern Asia. This massive consists of pre-Cambrian, very strongly folded and metamorphosed rocks, represented mostly by gneisses and crystalline shales together with granites. Toward the borders of this massive the ancient crystalline basement gradually disappears under a cover of Cambrian and Silurian marine deposits, which occupy all the remainder of the area of the North Siberian Shield, and lie transgressively on the Proterozoic basement. The Lower Paleozoic formations are almost horizontal, or plunge only slightly toward the borders of the shield. In a general way, they do not reach any considerable thickness, although toward the borders of the shield their thickness is greater than in the immediate vicinity of the Anabar massive. The Cambrian deposits are represented mainly by red or light gray limestones and by marls with *Archaeocyathydae* and *Anomocare excavatum*. The Silurian deposits, which

lie conformably on the Cambrian are represented mainly by limestones with a rich fauna of *Orthoceras virgatum*, *Asaphus*, *Amphyon*, *et cetera*, and by red formations.

From this brief description it can be easily seen that the North Siberian Shield does not offer any interest from the viewpoint of petroleum exploration, with the possible exception of the border zones of the shield. No definite judgment can be formulated at present, because these border zones are not sufficiently explored.

ALDAN SHIELD

Almost the same characteristics apply to another ancient shield southeast of the first one, and occupying the basin of the Aldan River (right affluent of the Lena). This is also a very large block, 1,200 kilometers in length and 400 kilometers in width. The crystalline core of pre-Cambrian rocks extends as a broad belt along the southern border of this shield, whereas the larger northern part of it is occupied mainly by transgressive Cambro-Silurian deposits. This northern border zone of the Aldan Shield has been fairly thoroughly explored during the last 10 years and, though previously it was assumed that the Cambrian deposits in this area were too thin and too horizontal to be of any practical interest, it appears now that these deposits, particularly in the basins of the Tolba, Botoma, and Amga rivers, include important formations of bituminous rocks and, moreover, that the tectonic structure of these deposits is not so unfavorable as had been thought. Thus, the northern border of the Aldan massive is considered now as one of the most interesting objects for further explorations. A detailed description of the stratigraphy of this region and of the work, which has been carried out therein during the last few years, is given in the second part of this article.

LENA-VILUJ DEPRESSION

Between the two previously described ancient shields there is a large depression, which is usually called the Lena-Viluj depression according to the names of the two largest rivers, which cross it. In the northeast this depression is limited by the Verkhojanski Mountain ridge, in the northwest and southeast by the North Siberian and Aldan shields, respectively. The southern and southwestern borders of this depression can be traced only approximately since there is no sharply marked limit, which would separate it from the so-called Lena-Yenisei field, located southwest of it.

Within this triangular depression, the ancient pre-Cambrian basement is located at a considerable depth, which naturally increases in the central part. This basin is filled by Cambro-Silurian deposits, the general characteristics of which are, however, entirely different from those of the same deposits in the neighboring shields. In the first place, the Cambro-Silurian formations reach here a very great thickness, exceeding at places several thousand meters. In the second place, the Caledonian orogenic movements have folded them into a series of

broad, gently dipping structures; this applies especially to the border zones of the depression, that is, to the transition areas between shields and depression. The lithological sequence of the Cambro-Silurian deposits can be briefly summarized. The Lower Cambrian is represented by a very thick series (800 meters) of dark, bituminous, marine limestones with numerous intercalations of black oil shales. These are covered by equally thick limestones and marls, together with sandstones and clays. In the axial part of the depression the Cambro-Silurian formations gradually plunge to a relatively great depth and this axial basin is again filled by transgressive Mesozoic (principally Jurassic) formations. These were also compressed into gently undulated folds probably during the Cimmerian orogenic phase.

In the western part of the depression the presence of several brachy-anticlinal and/or domal structures has been observed, the cores of which consist of strongly dislocated Cambrian formations, containing apparently fairly large saltstocks, whereas the flanks are built up by Mesozoic deposits. In the basin of the Viluj River these belong to the lower Dogger (Middle Jurassic). They consist of various clays with sphero-siderites and sandstones, and contain a rich fauna: *Belemnites elongatus, B. pyramidalis, Harpoceras murchisonae, Tancredia, Mytilus, Nucula, Leda, Ostrea, Hinnites, Rhynchonella, Icthyosaurus, Eretmosaurus.* The thickness of these marine Middle Jurassic deposits is 100–150 meters. On the contrary, the Upper and Lower Jurassic are developed in the same basin as a fresh-water facies, wherefrom it can be concluded that the ingression of the Jurassic sea into the basin of the Viluj River lasted only a relatively short time and that the shore line was not located at a great distance.

Various surface petroleum indications, some in the form of regular seepages, but most as bituminous and oil shales, as well as asphalt occurrences in the Paleozoic rocks, are reported from different parts of the Lena-Viluj depression. This fact, together with the lithologic composition of the sedimentary formations and the general tectonic structure of this region, has induced the Russian geologists to consider it as one of the most promising territories of the Siberian continent.

KHATANGA DEPRESSION

Almost the same can be said about the Khatanga depression, which occupies the lower part of the basin of the Khatanga River, flowing into the Arctic Ocean. It is located between the North Siberian Shield in the south and the strongly dislocated Hercynian zone of Paleozoic formations making up the Taimyr Peninsula in the north. It is possible that along the northeastern edge of the North Siberian Shield, coinciding with the valley of the Lena River, there is a narrow strip of territory (limited on the east by the Verkhojanski Mountain ridge) by means of which these two depression are connected.

The principal difference between the Lena-Viluj depression and the Khatanga depression is that the latter (with the exception of the immediate coast line of the Arctic Ocean) is even less known geologically than the former, and that the

conditions of exploration work within the almost uninhabited arctic tundra region are even more difficult than in the region of forests and marshes of central Yakutia.

TUNGUSIAN BASIN

This vast area is limited in the north by the folded Paleozoic zone of the Taimyr Peninsula, in the east by the western borders of the Khatanga depression and of the North Siberian Shield, and in the west by the middle and lower course of the Yenisei River, that is, by the eastern border of the West Siberian Plain. This plain is separated from the Tungusian basin by a very long line of faulting, extending along the Yenisei River, or slightly west of it. The southern limit of the Tungusian basin can not be determined accurately, but in a general way it coincides with the watershed line between the basins of the two large left-side affluents of the Yenisei River: the Podkamennaya (or Middle) Tunguska (which on some maps is also called Khatunga, not to be confused with the aforementioned arctic Khatanga) and the Angara, also called Verkhniaya (or Upper) Tunguska.

Structurally this region occupies an intermediary position between the shields and depressions, and it can best be described as a shallow basin. The Proterozoic basement dips very gently from the border of the North Siberian Shield toward the central part of the basin, continuing thus in the same general trend which characterizes it in the border zones of the shield. Toward the western border of the Tungusian basin the Proterozoic basement rises again, here somewhat more abruptly, and reappears at the surface at various places along the middle and lower course of the Yenisei River. These outcrops of Proterozoic rocks are interpreted by some geologists as remnants of a belt of folds surrounding the Archean Central Siberian continent and, therefore, having the character of typical border folds, their origin being due to the resistance offered by this compact block to Proterozoic orogenic movements. Other and better preserved remnants of this belt of outcropping Proterozoic formations may be observed south of the Tungusian basin, in the area of the so-called Yenisei horst.

The stratigraphic section of sedimentary formations filling this basin starts with a strong sequence of marine Cambro-Silurian deposits. Their thickness gradually increases toward the west. They lie transgressively and almost horizontally on the strongly folded Proterozoic basement. Only in the western part of the basin, in the vicinity of the Yenisei River, these Cambro-Silurian deposits have been folded into a series of gently dipping structures. In this part of the basin some of the Silurian formations contain fairly important bituminous shales, as well as porous dolomites with indications of solid and semi-liquid bitumens. The Cambro-Silurian formations are followed by Devonian sediments and these are covered in very large areas by the coal-bearing, continental formations of the so-called Tungusian series, under which name Russian geologists usually group all the continental formations of Upper Paleozoic age (Carboniferous and Per-

mian, also partly Devonian) in central and western Siberia. These Upper Paleozoic formations are, however, continental in facies; only in the very western part of the Tungusian basin some intercalations of marine limestones are found among the otherwise continental or lagoonal formations of the Tungusian series.

The foregoing leads to the conclusion that whereas the greater part of the Tungusian basin can be eliminated from the list of promising oil-bearing regions at least in the present state of knowledge, the possibilities of its western part, especially along the lower courses of two right-side affluents of the Yenisei River, the Nijniaya Tunguska and the Sukhaya Tunguska, merit immediate consideration. This area is generally known as the Turukhansk oil-bearing region. It extends along right-side affluents of the Yenisei but the town of Turukhansk is on the left bank of the river. Nevertheless, this name is justified, first because Turukhansk is the only somewhat larger inhabited center in all this vicinity and secondly because the line of faulting, separating the Tungusian basin from the West Siberian Plain, extends west of Turukhansk, so that from a geological standpoint this town in still located within the Central Siberian Platform and not in the West Siberian Plain. A special section in the second part of this article is devoted to a more detailed description of the stratigraphic and tectonic structure of the Turukhansk oil-bearing region and of the recent exploration work.

Farther north, in the region of the estuary of the Yenisei River, petroleum indications are known in the Ust-Port area, mainly as gas emanations. However, as they seem to be connected with disjunctive dislocations in Cretaceous deposits, their study does not appear to be directly connected with the problem of the Cambrian oil in the Central Siberian Platform.

LENA-YENISEI FIELD

The southwestern part of the Central Siberian Platform is occupied by the so-called Lena-Yenisei field, which is limited in the north (from west to east) by the Tungusian basin, the North Siberian Shield, and the Lena-Viluj depression. In the south it is bordered (from west to east) by the Sajany Mountain ridge, Lake Baikal, and the Transbaikal Mountains, and in the west by the West Siberian Plain.

In this vast region the Proterozoic basement lies at considerable depth. Only in the west, along the right bank of the Yenisei River, between the towns of Yeniseisk and Tungusk, this ancient crystalline basement comes to the surface and forms a typical horst structure, bordered on all sides by strongly marked fault lines. The entire area of the Lena-Yenisei field is covered by Cambro-Silurian deposits of great thickness. In the central parts and in the north of this field these deposits are almost horizontal, whereas along the borders, especially in the south, folded structures make their appearance, and at places the Lower Paleozoic formations are even considerably broken. Lithologically these formations are characterized by the presence of dark, in places bituminous, limestones.

Along the southwestern border of the Lena-Yenisei field, in the area which

adjoins the Eastern Sajany Mountain ridge, there are several depressions filled by continental Mesozoic coal-bearing formations, which rest unconformably on Lower Paleozoic deposits. From the viewpoint of petroleum geology these depressions, among which the best known in the Irkutsk coal-bearing basin, do not seem to offer any practical interest.

On the contrary, the inner border zone of the Lena-Yenisei field merits special attention. This zone includes a broad belt extending north of the Trans-Siberian Railway between the towns of Krasnoyarsk and Irkutsk (particularly in the vicinity of Usolsk and Nijne-Udinsk), also the watershed area between the upper courses of the Lena and of the Angara rivers (vicinity of Ilimsk, Kutsk, and Kirensk), and finally the area east of the Yenisei horst (basin of the Velmo River). All of this zone contains a fairly large number of favorable, partly brachyanticlinal structures, as seems to have been proved by recent discoveries. These structures are formed by Cambrian formations, which include very thick bituminous deposits. Emanations of combustible gases and salt springs are also known in various parts of this zone.

WEST SIBERIAN PLAIN

The geographical limits of this region are defined in the introductory part of this chapter. A subdivision of this enormous territory into smaller geological units is impossible for the moment, because its underground structure is almost entirely hidden by a fairly thick cover of horizontal Quaternary deposits (marine in the north, and continental in the south), so that before all of this area is thoroughly tested by means of geophysical methods, an approximate idea of this subsurface structure can be obtained only by studying the outcrops of older rocks, which appear at the surface in the border zones of this plain, particularly its eastern and southern borders.

We have already seen that practically all Paleozoic deposits are developed in a marine facies along the borders of the West Siberian Plain, that is, on the eastern slopes of the Ural Mountains and in the northern part of the Kasakstan. These Paleozoic deposits have been strongly dislocated, particularly during the Caledonian orogenic phase, and partly also during the Hercynian phase. They have also been metamorphosed to some extent by strong intrusions. Toward the West Siberian Plain these Paleozoic deposits plunge under a cover of Mesozoic and Cenozoic formations and it does not seem that the intensity of their dislocation decreases in this direction.

Thus it is certain that within the West Siberian Plain the basement is represented by a massive of strongly dislocated Paleozoic rocks, considerably affected by magmatic intrusions. Recent geophysical explorations seem to have shown that this basement is not flat, but that on the contrary it has a number of uplifts with dips ranging up to 14°.Whether these uplifts can be considered as having possibly caused any accumulations of oil can not be decided at present. The absence of any petroleum indications in the Lower Paleozoic formations in the

eastern Urals and in the southern Paleozoic belt extending from the Turgai region to the Salair Mountains is not a hopeful sign as regards the western part of the West Siberian Plain. On the other hand, one may assume that the prospects are somewhat better in its eastern part, especially if it is definitely proved that exploitable petroleum reserves exist along the western border of the Central Siberian Platform and in the basins of Minusinsk and Kuznetzk.

The Lower Mesozoic deposits (Triassic and Lower Jurassic) are developed in a continental or lagoonal, coal-bearing facies along the eastern slopes of the Urals and in the hill and mountain region, bordering the West Siberian Plain on the south. Some Russian geologists, and among others the well known Academician Gubkin, have expressed the opinion that this continental, coal-bearing facies of the Lower Mesozoic gradually changes into the marine, bituminous facies toward the central part of the plain. While this opinion is supported by various theoretical considerations, it not confirmed in practice.

Finally, the Upper Mesozoic and the Triassic deposits are represented in the West Siberian Plain mainly by typical epicontinental sediments, glauconitic sands, clays, *et cetera*, in which it is almost impossible to expect to discover primary petroleum accumulations.

It can be seen, therefore, that the West Siberian Plain does not offer any immediate prospects, and while no final judgment can as yet be formulated, it is certain that this vast area is one of the most difficult objects to be studied by the Russian petroleum geologists and that a very great amount of geophysical work and of test drilling will have to be done before arriving at any definite conclusions regarding the practical value of this region.

SOUTH SIBERIAN MOUNTAINS

South of the West Siberian Plain and the Central Siberian Platform there extends a broad mountain zone, consisting of various mountain ridges, such as the Salair, the Kuznetzky Alatau, the Altai and the western and eastern Sajany. In the main these mountain ridges consist of pre-Cambrian and Cambrian rocks, as well as of intrusive formations. The sedimentary formations are very strongly metamorphosed and dislocated. The main folding phenomena have taken place during different Proterozoic orogenic cycles, but principally during the Caledonian phase; therefore, this entire zone is often referred to as the Caledonian zone.

Thus, as a whole, this zone does not offer any interest from the viewpoint of petroleum geology and for this reason a detailed description would be out of place in this article. However, it must be mentioned that within this Caledonian mountain zone there are two large depressions, which owe their origin precisely to Caledonian movements and which have later been filled by Devonian and Upper Paleozoic deposits (partly also Mesozoic). While these two depressions (the Kuznetzk and the Minusinsk basins) are well known all over the world because of the enormous coal reserves in the Upper Paleozoic deposits, it seems that

the underlying marine Devonian deposits offer some possibilities as regards the formation and accumulation of practically important oil reserves. It is, therefore, necessary to say a few words about each of these basins.

KUZNETZK BASIN

This basin is situated south of the Trans-Siberian Railway line and orographically it coincides with the basin of the Tomj River. It is about 250 kilometers long and 100 kilometers wide. On the southwest it is bordered by the Salair Mountains and on the northeast by the Kuznetzk Alatau ridge. The Kuznetzk depression was formed during the Caledonian orogenic phase, so that the Devonian sea could freely penetrate in it from the north. This is confirmed by the fact that, though in the southern part of the basin the Devonian deposits consist mainly of conglomerates, sandstones, and similar sediments, which indicate the vicinity of the shore line, in the north they are represented by finely grained, uniform clayey shales, characteristic of pelagic sediments. These shales are commonly sapropelitic. During subsequent orogenic phases (Hercynian *et cetera*), the Kuznetzk depression was transformed first into a semi-closed and later into a completely closed basin by the rising of Devonian folds in the north. Thus the Upper Paleozoic (Carboniferous and Permian) and the Mesozoic (chiefly Jurassic) formations were deposited under the conditions of a shallow marine regime, which frequently passed over into a lagoonal or even a completely terrestrial regime. The bottom of the basin continued to sink during all this time and it is in this way that thick coal-bearing deposits could be formed. It should be noted that whereas the Upper Carboniferous and the overlying formations are characterized by enormous coal reserves, the Lower Carboniferous is represented at places by dark, bituminous limestones. The Hercynian and subsequent orogenic cycles strongly affected the framework of the basin, so that in its border zones the Devonian formations are fairly intensely folded. They, as well as the underlying Lower Paleozoic basement rocks, have moreover been broken into a number of blocks, which have been pushed toward the inside of the basin. On the contrary, in the inner parts of the Kuznetzk basin the Devonian formations have been only slightly folded and seem to offer a number of favorable structures.

MINUSINSK BASIN

The Minusinsk basin is situated east of the Kuznetzk basin, and it is separated from it by the Kuznetzk Alatau Mountain ridge. On the south and on the east it is bordered by the Western Sajany ridge. The basin is about 200 kilometers long and 100 kilometers wide. The Yenisei River crosses it from south to north in its upper course. The main structural features of the Minusinsk basin are very similar to those of the Kuznetzk basin: they consist of a strongly dislocated framework of metamorphosed Cambrian deposits, with a large proportion of effusive and intrusive rocks, and of a much less disturbed inner part built up by marine Devonian deposits, covered in turn by coal-bearing Upper Paleozoic

and Jurassic formations. The Devonian deposits show, in brief, the following sequence: bottom conglomeratic and other detritus formations are followed by bituminous limestones of the Middle Devonian, and these in turn are covered by red Upper Devonian deposits.

Within the Minusinsk basin several brachy-anticlinal structures have been discovered, but in most of them the cores have been completely or partly eroded.

It should be noted that no surface petroleum manifestations are known either in the Minusinsk basin or in the Kuznetzk basin, and that, therefore, all the hopes for the discovery of exploitable petroleum reserves in these two basins are connected exclusively with the presence of bituminous formations in the Devonian sediments and of favorable tectonic features.

Thus, it can be seen that the petroleum problem in the western part of the South Siberian Mountains is entirely different in character from the same problem in the Central Siberian Platform, in the first place, as regards the age of the promising formations (Devonian instead of Cambro-Silurian) and secondly, because the whole problem is limited to a comparatively very small and strictly defined territory. Finally it should be kept in mind that apart from the size of the problem, the practical conditions of work will be much easier in the coal basins than in Central Siberia. The coal basins are situated well outside the zone with perpetually frozen ground, they are fairly thickly populated, and all their parts are within easy reach from the large industrial centers and railway lines. For all these reasons it appears that the problem of the Devonian oil in the South Siberian coal basin is a comparatively easy one and that a definite answer regarding the possible practical value of these territories could be obtained within a relatively short time. On the other hand, it is clear that even if exploration work within the coal basins is crowned by complete success, the theoretical possibilities offered by these territories are decidedly smaller than those of the almost unlimited spaces of the Cambrian zone of Central Siberia.

BAIKAL ZONE

East of the Caledonian zone is the so-called Baikal zone of folds, which includes the Eastern Sajany Mountain ridge and the broad belt of Transbaikal Mountains, located between Lake Baikal and the relatively much younger Yablonovi ridge. A northeastern extension of this zone is formed by the much narrower strip of territory located between the Aldan massive and the Stanovoy Mountain ridge. The Baikal zone is a very ancient region, consisting mainly of Archean and Proterozoic metamorphosed formations, large spaces being also occupied by igneous rocks. The main tectonic features of the Alpine type (folds) originated in this region during the various Proterozoic phases. Later orogenic movements did not result in the formation of new folds, but manifested themselves rather in dislocations of the Germanic type: faults, overthrusts, *charriage* phenomena, *et cetera*. Parts of this territory were thus divided into blocks, some of which were lifted, whereas others sank which resulted in the appearance of

structures of the horst and of the graben type. Lake Baikal itself is considered by some Russian geologists as a graben structure, somewhat similar to the Dead Sea.

While the greater part of the Baikal zone can safely be excluded from the list of promising territories, the southern and eastern shores of Lake Baikal itself merit special consideration. Liquid oil seepages, very strong and numerous emanations of combustible gases, and accumulations of ozokerite have been observed in this area in quantity unknown elsewhere in Siberia. Much time, effort, and money have been spent for general exploration and test drilling in the Lake Baikal area since the beginning of this century, and especially during the last 10 or 12 years, but somehow it appears that all this work has been conducted somewhat unsystematically, and, at any rate it has not been crowned by any success. Not only no commercially exploitable reserves were discovered, but even the most fundamental question about the origin of the hydrocarbons has not yet been solved. The stratigraphic sequence on the southern shores of Lake Baikal is briefly as follows (from top to bottom): coal-bearing Tertiary deposits lie directly and unconformably on fissured Proterozoic gneisses, which seem to be underlain by Paleozoic formations, which would indicate the presence of a *charriage*. It has been impossible to determine with certainty whether the oil and gas manifestations come from the Tertiary or from the much deeper Paleozoic deposits.

MOUNTAIN REGION OF EASTERN SIBERIA

Eastern Siberia is orographically separated from the Central Siberian Platform and from the South Siberian Mountains by an extremely long belt of mountain ridges, which bear the names of Verkhoyanski, Stanovoj, and Yablonovy ridges. These ridges consist mainly of ancient strongly folded rocks with a very considerable proportion of magnetic intrusions, but their present orographic configurations are due mainly to the action of relatively more recent orogenic movements, which manifested themselves not so much by folding phenomena as by disjunctive dislocations, overthrusts, *charriage* phenomena, *et cetera*.

Only about 15 years ago the region east of the Verkhoyanski Mountain ridge was *terra incognita* not only from the standpoint of petroleum geology, but, in many respects, even from a geographical standpoint. At present the main features of the geological structure of some parts of this region are already cleared up, but still very much remains to be done before any judgment can be pronounced regarding the petroleum possibilities. As already indicated in the historical part of this article, vast areas of this region consist of marine Mesozoic deposits (particularly in the basin of the Yana River), which at places seem to offer favorable structural conditions for the accumulation of petroleum. On the New Siberian Islands bituminous limestones and shales are known in Paleozoic and Mesozoic deposits. The same applies to the upper basin of the Omolon River and to the basin of the Anadyr River.

The other (southern) part of Eastern Siberia, situated east of the Yablonovi ridge, is generally known as the Amur belt, by the name of the largest river crossing this region, which extends from the Sea of Okhotsk on the northeast into Mongolia in the southwest. Its general structure is similar to that of the area of the Stanovoy and Verkhoyanski ridges. The strongly folded Upper Paleozoic and Mesozoic formations of this region have later been affected by disjunctive dislocations with numerous *charriages*, so that at many places the Mesozoic formations are covered by metamorphosed Paleozoic and perhaps even pre-Cambrian rocks. Post-Jurassic intrusions of granites and recent effusions of basaltic lava are characteristic for this region.

Indications of hydrocarbons are fairly numerous in this region. Thick layers of bituminous shales have been observed in various Mesozoic formations, particularly in the Lower Cretaceous. Fissures and pores of the volcanic rocks commonly contain accumulations of hard or semi-soft bitumens, their origin being probably due to the action of magma intrusions into the coal-bearing or bituminous shales. The petroleum possibilities of this region merit a serious and detailed study, but the unfavorable tectonic conditions do not make it appear probable that the prospects are very great.

Along the eastern coast of Siberia is a belt of young Tertiary folds, embracing principally the Kamchatka Peninsula and the Island of Sakhalin. This belt contains numerous oil indications and on Sakhalin the exploration of these indications has already resulted in the creation of an important petroleum industry.

CONCLUSION

The foregoing summary of the various geological areas of the Siberian mainland leads to the following conclusions.

While the enormous Siberian territory is relatively poor in actual petroleum indications, in the form of seepages (which may be partly due to the location of a very large part of Siberia, in the zone of permanently frozen ground), there are within this territory vast areas, which, by the lithological composition and the tectonic structure of the sedimentary formations, seem to offer favorable possibilities. Exploratory work during recent years leads to classification of such areas and to selection of those meriting special consideration. These areas are the following.

1. Northern slopes of Aldan massive and adjoining Lena-Viluj depression (Cambrian)
2. Northwestern part of Tungusian basin, near town of Turukhansk (Cambrian)
3. Khatanga depression and its western extension within Tungusian basin, south of Taimyr folded zone (Cambrian and partly Mesozoic)
4. Basins of Kuznetzk and Minusinsk (Devonian)
5. Baikal Lake area (Tertiary?)

The fourth part of this article is devoted to a somewhat more detailed, chiefly stratigraphic description of these five areas and of the exploration work in each of them.

Part IV. Detailed Stratigraphic Description of Siberian Oil-Bearing Regions

Northern slopes of Aldan massive and adjoining Lena Viluj depression

In 1934 the Geological Institute for Petroleum Research, the administration which directs all the exploration work for petroleum in the entire territory of the U.S.S.R., started the study of the Cambrian sediments in the upper basin of the Lena River.

The preliminary exploration work was completed by 1938, after the discovery of favorable structures and of numerous petroleum indications in the basins of the Tolba, Botoma, and Amga rivers (southern affluents of the Lena River).

Because the folding phenomena are only very slightly developed in the Cambrian sediments, which form this region, it has been necessary to carry out tachymetric surveys in order to determine the position of the surface beds. On the other hand, it must be remembered that the region under study is covered by forests and marshes, and that means of communication are almost completely lacking. In practice, due to the lack of communications, this immense region was almost inaccessible. In 1941, two meridian automobile roads, more than 1,300 kilometers long, were completed after 5 years. The greatest attention was paid to the basin of the Tolba River, where the drilling of a test well was started by the end of 1938. This is in fact the region where outcrops of raw petroleum were found at the same time the stratigraphical and paleontological studies led to the discovery of salt domes of the Cambrian age. This well reached a depth of 373 meters. However, the yield of the oil which was obtained at a depth of 372 meters did not exceed 86 liters per day. Between the depths of 139 and 140 meters slight gas flows were encountered. Traces of liquid and semi-liquid petroleum, commonly found during the drilling, are connected with the fissured limestones of the upper part of the Lower Cambrian sediments. In 1939 it was planned to drill more exploration wells in the Cambrian sediments of the Lena River basin. Unfortunately the outbreak of the second world war put an end to the possibility of receiving here the Russian publications devoted to petroleum questions, and thus we are not in a position to judge the results of the last 4 years. We must really admire the formidable efforts of technicians who endeavored to find petroleum in a region where the temperature falls to 60° below zero and where the zone of frozen ground reaches the depth of 100 meters.

The described region of the upper course of the Lena River forms a part of the Siberian Platform and has a uniform, almost flat relief. Its relative elevation does not exceed 300 meters. The principal water artery is formed by the Lena River, which runs along the northern border of the region. The Tolba, Botoma, and Amga rivers, which cross it, are southern affluents of the Lena.

The stratigraphy of the Cambrian sediments of the upper basin of the Lena River may be summarized as follows.

The region is formed by a rather uniform complex of Cambrian rocks. These are represented by calcareous marls, and by dolomites, and are very slightly affected by diagenetic phenomena. Fossil remains are also very few. The entire sequence of Cambrian sediments may be subdivided into four series, on the basis of the lithologic character. Of these, the three lower series belong to the Lower Cambrian, and the upper (fourth) series to the base of the Middle Cambrian.

The Lower Cambrian sediments start with a red series, the visible thickness of which reaches 80 meters, and which, from the lithologic standpoint, is represented by an alternation of dolomitized limestones and of marls. The marls are calcareous, sandy, or argillaceous; some organic remains in a very poor state of preservation are found in the marls; probably they belong to *Hyolites* sp. This marly series is commonly characterized by the presence of asphalt, which is found in breccias of calcareous marls. The rocks of this first Cambrian series are almost horizontal with a very slight dip toward the north or northeast.

The second Lower Cambrian series (intermediary series) is known in the local geological literature under the name of "Lower calcareous series." This second series is conformable on the red series. Its visible thickness is about 30 meters. The lower part of this second series is represented by very stringy silicified limestones. The upper part is formed by finely stratified limestones with *Collenia undosa*. Just as the red series, the intermediary series of the Lower Cambrian is almost horizontal. At places where eruptive rocks make their appearance, the dip of the beds is slightly greater and varies between 0° and 3°.

The third series of the Lower Cambrian (upper series) is represented by bituminous dolomites of a visible thickness of 90 meters. These dolomites, which form the top of the Lower Cambrian, are conformable on the lower sediments. They are characterized by rather important petroleum indications. In general, this bituminous series is represented by coarsely stratified, commonly sandy dolomites. At the places where these dolomites are strongly bituminized, they are finely stratified and are, for this reason, characterized by a dark gray color. In the fissures and in the caverns, accumulations of asphalt can be observed. The porosity of these bituminous dolomites varies between 8 and 5 per cent of the total volume of the rock. The dip of this series of bituminous dolomites is very slight, not more than 2°NE.

The base of the Lower Cambrian, which terminates the stratigraphic profile of the sedimentary series of the upper basin of the Lena River, reaches a visible thickness of 100 meters. These sediments are known in the local geological literature as "Upper calcareous series." From the lithologic standpoint the Middle Cambrian is characterized by limestones and dolomites irregularly and indistinctly stratified. The dip and the strike of the Middle Cambrian formations are the same as the dip and strike of the underlying bituminous dolomites of the Lower Cambrian. The Middle Cambrian is characterized by abundant secondary petroleum indications in the form of solid bituminous inclusions within the fissures and the pores of the rocks.

From this brief description of petroleum indications in the upper basin of the Lena River, it can be seen that the potentialities of this region for the production of petroleum are still in the stage of preliminary studies.

NORTHWESTERN TUNGUSIAN BASIN NEAR TURUKHANSK

As already mentioned, the in region of the Yenisei River and of its affluents, the Sukhaia Tunguska and the Nijniaia Tunguska, carbonate rocks are developed over large areas (at some places they are represented by Lower Cambrian black shales). The color of these black clayey shales is due to the presence of traces of bitumen.

The presence of three anticlinal folds has been determined in different parts of this region. These structures are accompanied by clearly expressed, secondary petroleum indications in the form of plastic and viscous bitumens and, at isolated places in the form of rather large pockets of relatively soft asphalt.

The first among these anticlinal folds is situated in the Sukhaia Tunguska River, at a distance of 14 kilometers from its confluence with the Yenisei River. The second favorable structure is located still nearer the estuary of the Sukhaia Tunguska (at a distance of only 500 meters). Finally, the third favorable structure, which, just as the first two, is outside the zone of permanently frozen ground, is located on the left bank of the Nijniaia Tunguska River, 54 kilometers from the town of Turukhansk.

It is interesting to state that these three anticlines are related to rather strong salt springs, some of which are also gas-bearing.

Sedimentary formations of various ages compose the geological structure of the region of Turukhansk, the sedimentary series not being everywhere complete. However, for the sake of clarity, we now give a brief description of the complete sedimentary series which forms the oil-bearing region of Turukhansk.

Quaternary
Devonian or Permo-Carboniferous (?)
Upper Silurian
  Diavolskaia series
  Bolsheporojskaia series
Lower Silurian
  Pokosnaia series
  Kostinskaia series
  Platonovskaia series
Unconformity
Cambrian (?)
  Miroiedikhinskaia series
Unconformity
Proterozoic complex
  Burovaia series
  Derevnskaia series
  Sukho Tunguska series
  Linok series
Unconformity (?)
  Beźimiannaia series

The ancient Proterozoic complex, the thickness of which reaches 2,500 meters, is divided into two distinctly different parts. The lower part represented

by the Bezimiannaia series, is formed by terrigenous sediments. The upper part, represented by the series of Linok, Sukho Tunguska, Derevninskaia, and Burovaia, is formed almost exclusively by carbonate rocks: dolomites and limestones.

The Bezimiannaia series is formed, in its lower part, by quartzites, and in its upper part by dark gray shales; its thickness is not less than 500 meters.

The Linok series is represented by compact limestones of greenish gray or pinkish gray color; its thickness is about 500 meters.

The Sukho Tunguska series reaches a total thickness of 650 meters. The lower part (first 200–250 meters) is formed by dark gray, black, or ash gray limestones and dolomites with algae of the *Collenia* sp. The upper part of this series consists of gray or yellowish gray dolomites.

The Derevninskaia series is represented by gray, reddish, orange, and greenish limestones and dolomites. The total thickness of this series varies between 350 and 370 meters. In the central part of the Derevninskaia series there is a bed of black and brown coal shales with intercalations of quartzites; the thickness of this coal-shale bed is 20–25 meters. It is a very good marker in geologic surveys.

The Burovaia series consists of gray and brownish gray dolomites with numerous intercalations of calcites, magnesites, and, less commonly, of limestones. The lithologic composition of the lower part of the Burovaia series is analogous with that of the underlying beds of the Derevninskaia series so that it is very difficult to determine exactly the demarcation between these two series. The thickness of the Burovaia series is about 800 meters.

The end of the Proterozoic age brought about an interruption in the sedimentation of exclusively carbonate rocks, which in this region possess such clearly marked characteristics. The geological formations above the Proterozoic sediments are represented by carbonate as well as by terrigenous rocks, however, with a certain predominance of the first.

The Cambrian beds rest unconformably on the lithologically uniform Proterozoic sediments. Here a clearly marked tectonic unconformity is definite evidence that the series belongs to the Cambrian and no longer to the Proterozoic formations. The Cambrian sediments are represented by only one series which is called the Miroiedikhinskaia series. From the lithologic standpoint, from bottom to top, this series consists of dolomites, red and green shales with concretions of pyrites, gray finely stratified limestones, and rather loose argillaceous shales with sandstone intercalations. The total thickness of the Cambrian reaches 900 meters.

The Lower Silurian deposits are subdivided into three series: Platonovskaia, Kostinskaia, and Pokosnaia.

The Platonovskaia series rests unconformably on the underlying Cambrian beds; this series is represented by a sequence of light brownish gray or greenish gray dolomites with intercalcations of shales; at the bottom of the Platonovskaia series small accumulations of solid bitumens can be observed; the total thickness of this series varies between 200 and 250 meters.

The Kostinskaia series of the Lower Silurian is represented by light yellowish or brownish gray dolomites, which are commonly cavernous. The thickness of this series reaches 1,000 meters; in its upper part it is characterized by accumulations of asphalt.

The last series of the Lower Silurian is the Pokosnaia series which is formed by an alternation of dolomites, shales, and argillaceous shales, of red or green color, with accumulations of solid and plastic bitumens. The thickness of this series is about 200 meters.

The Pokosnaia series is followed by the sediments of the Upper Silurian, which from the stratigraphic standpoint, may be easily subdivided into two series: a lower one, called the Diavolskaia, and an upper one, called the Bolsheporojskaia. The sediments of the Upper Silurian have practical significance because of the presence of liquid and semi-liquid bitumens.

The lower part of the Diavolskaia series (Upper Silurian) is represented by cavernous and porous dolomites, of gray or dark gray color. The dolomites are abundantly impregnated with liquid and semi-liquid bitumens. The thickness of these bituminous dolomites is 40 meters (incomplete because determined exclusively on the basis of natural outcrops). In the paleobotanic remains were found *Cirvanella, Conophyton, Collenia,* and in the corals, *Favosites gothlandiens, Halisites catenularia.*

The upper part of the Diavolskaia series, which rests conformably on the series of bituminous dolomites, is represented by limestones, shales, and dolomites. This upper part is only partly impregnated with bitumens. The visible thickness of this series is 25 meters.

The Bolsheporojskaia series is represented by sandstones, conglomerates, and shales of red and green color; its thickness is 200–250 meters.

It has been impossible to determine exactly the age of the uppermost sediments of the stratigraphic series in the region of Turukhansk, because of the absence or the poor state of preservation of the paleontological remains. However, it is estimated that this series belongs either to the Devonian or to the Carboniferous (in the local literature it is called the Tunguska series). It is represented by a sequence of black, dark gray and greenish gray compact shales; its total thickness is 300–350 meters.

We now examine briefly the tectonic structure of the region of Turukhansk.

In the region of the Nijniaia Tunguska the position of the beds, which in general are monoclinal with a westward dip, is complicated by numerous tectonic irregularities. This fact was the reason why the exploration work was at first concentrated in the region of the Sukhaia Tunguska, where the stratigraphic profile is the most complete. Thus, for example, the same well can explore the Proterozoic and the Paleozoic formations.

The region of the lower course of the Sukhaia Tunguska (near its confluence with the Yenisei River) represents the western flank of an anticline of enormous dimensions. The region is separated from the eastern flank by a very large fault.

This western flank of the anticline is complicated by a secondary fault. The western and eastern flanks dip very gently, not exceeding 5° or 6°.

The Silurian beds are much less affected by the folding than are the more ancient sediments.

The Upper Proterozoic series (Burovaia series) is characterized by bitumen in the fissures and caverns of the carbonate rocks.

The Lower Silurian formations are only slightly bituminous. In the lower part of the Platonovskaia series small accumulations of bitumens have been found. In the intermediate series of the Lower Silurian (Kostinskaia series) considerable accumulations of solid and semi-liquid asphalt have been discovered in the course of geological explorations. These asphalt accumulations form separate deposits of a thickness reaching 20 meters. The Lower Silurian ends with the Pokosnaia series in which small pockets of solid asphalt are rarely found.

Interesting occurrences of liquid and semi-liquid bitumens are found in the porous and cavernous dolomites, which form the lower part of the Diavolskaia series (lower series of the Upper Silurian). The bitumen forms accumulations by filling fissures of a thickness reaching 10 centimeters. These bitumens form a plastic mass which is easily liquefied under the influence of the rays of the sun during the summer months even in this almost polar region. The elementary analysis of this bitumen gives the following results.

	Percentage
C	83.36–83.84
H	9.65–10.76
N	0.30– 0.38
S	3.45– 3.72
O	1.74– 3.37

In addition to the filling of the fissures, bitumens were found also in several zones in the dolomites of the Diavolskaia series. These zones represent breccia-like and cavernous intercalations. The remainder of the dolomites of the Diavolskaia series is represented. in most places by different varieties of compact dolomites.

The Upper Silurian shales, which lie above the Diavolskaia series, form a good cover for the preservation of the bituminous accumulations.

The semi-liquid and solid bitumens, which fill the fissures and the caverns in the Burovaia series (Upper Proterozoic) in the nucleus of the anticline of the Sukhaia Tunguska, were discovered during the preliminary geologic investigations. These petroleum indications were of such considerable size that it was decided to drill a well at this place, on the banks of the Sukhaia Tunguska River 20 kilometers from its confluence with Yenisei River. The purpose of this test well was to explore the Proterozoic formations, which crop out at this place. In 1940 this well reached the depth of 600 meters. It did not encounter any commercially exploitable oil-bearing formations, but it did find traces of semi-liquid oil, or pockets of asphalt. Exploration of the Turukhansk region proved that it is difficult to expect commercially exploitable petroleum accumulations in

the Proterozoic formations in which there are no beds which could be reservoir beds. Furthermore, the Middle and Lower Proterozoic series do not contain any petroleum indications. It is interesting to note how sometimes the work of the geologist is accompanied by bad luck. During the later geological explorations in the region of Turukhansk it was demonstrated that the Burovaia series (Upper Proterozoic) crops out at many places in this vast territory; but at no other place does it contain any petroleum indications; thus, the location, where the first exploration well of the Turukhansk region was drilled is the only one where the Burovaia series possesses local petroleum indications, this fact having induced the geologist to locate precisely at this place the first test well.

According to the plan of the Geological Institute for Petroleum Research subsequent exploration work for petroleum in the region of Turukhansk had to be concentrated (beginning with 1941) on the study of the petroleum possibilities offered by the Upper Silurian formations.

KHATANGA DEPRESSION AND ITS WESTERN EXTENSION WITHIN TUNGUSIAN BASIN SOUTH OF TAIMYR FOLDED ZONE

The Khatanga depression includes the basin near the mouth of the Arctic Khatanga and Anabara rivers.

West of the Khatanga River on the peninsula of Taimyr, it was still possible to find, in 1905, massive mineral salt of Silurian age (H. H. Pinkow). These saliferous deposits are being worked.

In 1933, in the region surrounding Cape Nordwik, the presence of many petroliferous outcrops was verified, where during the summer, under the action of the polar sun, they form puddles of liquid petroleum. Also, it has been verified that in the southern part of the depression of Khatanga, which is adjacent to the Anabar massive, indications of petroleum and asphalt were present in the lower parts of calcareous rocks (Middle Cambrian) as well as in cavernous calcareous and superposed dolomites.

Therefore, the presence of saliferous structures and indications of petroleum gave impulse to exploration work on this shore of the Glacial Ocean.

Since 1934, geophysical studies are fully developing under the direction of the well known polar explorer, Otto Schmidt.

In a short time geophysics verified the presence of characteristic saliferous manifestations, and more than 20 structures, favorable for the accumulation of petroleum, were soon found.

As soon as the Krelius-type drill apparatus arrived, drilling was begun.

First, wells were drilled on the northwestern border of Nordwik Peninsula. Wells reach 620 meters in depth, go through the gypseous cover, and pierce into the saliferous massive. Subsequent wells, drilled through the sides of the salt domes, confirmed the presence of Mesozoic and Cenozoic sediments, and well defined breccias appear in the contact zone.

Indications of bitumens appear at various depths, but the most petroliferous

zone is at an average depth of 500 meters; sandstone, probably of Lias age is found here.

Other wells were undertaken in the areas bordering the Bay of Khatanga with the purpose of finding the horizontal extent of petroliferous rocks.

All these wells proved the presence of petroliferous rocks of Paleozoic and Mesozoic age throughout this country, which is bordered on the north by the Glacial Ocean and contains the interior basins of the Khatanga and Anabara rivers.

During this drilling an unsuspected fact was established that the phenomenon of the permanently frozen ground continues to the depth of 620 meters at least as the deepest wells have not yet gone through this zone of frozen sediments.

At 330 meters in depth, the thermometer shows 14° F. below zero.

It is clear that, due to such geothermic conditions, a new technique must be found to exploit the petroleum of these wells, frozen by Nature.

OIL-BEARING REGION OF KUZNETZK BASIN AND MINUSINSK BASIN

KUZNETZK BASIN

The northeastern part of the Kuznetzk coal basin represents a trough filled with Devonian sediments and covered with thick beds of the Carboniferous period. This basin is assumed as probably oil-bearing because the following considerations from the geological point of view.

First, several Devonian formations are characterized (in the region of the Barzass River) by the presence of asphaltites. Asphaltic beds are found in Carboniferous formations (productive in the Kuznetzk basin).

The bituminous shales are to be construed as intercalations in the Devonian sediments and also, but very rarely, in the part lower of the Carboniferous.

Finally, the deposits of the sapropelic coal in the Devonian sediments induce us to consider that the bio-stratigraphical conditions could be favorable also to the formation of petroleum. This sapropelic bed, called "Sapromixit" contains 10 per cent of hydrogen while the petroleums contain 12 per cent of hydrogen.

For the time being, nothing is known with precision about the economic possibilities of this basin, supposedly petroliferous only from the theoretical point of view.

BASIN OF MINUSINSK

The Middle Devonian formations of the Minusinsk basin are essentially represented by a thick series of red sediments, which contain several zones of bituminous rocks. Most of these bituminous rocks consist of limestones and clayey shales; it is hoped that it will be possible to find in them primary accumulations of petroleum.

Secondary indications of petroleum continue to the Upper Devonian and, at places, even to the Lower Carboniferous. They are observed in the Minusinsk basin in the form of asphalt veins, although they extend over a considerable

area (particularly in the region of the left bank of the Yenisei River); they are, on the other hand, not very numerous.

The Minusinsk basin occupies a vast territory on the banks of the Yenisei River, in the upper part of its course.

All the mountainous rocks bordering the Minusinsk basin consist of sedimentary, in many places metamorphosed formations. These formations belong to the Cambrian, or to the Silurian; the lower formations consist of pre-Cambrian sedimentary rocks.

The Minusinsk basin is filled by a series of sedimentary formations of marine or semi-continental origin; these rocks belong to the Devonian sediments, and, in their upper part, to the Carboniferous and Permian systems.

The sediments of the Middle Devonian fill the bottom of the Minusinsk basin and extend as an almost uninterrupted band all around this basin, forming thus its border zone. These Devonian sediments dip toward the center of the basin, plunging under Upper Devonian sediments, as well as Carboniferous and Permian beds, which fill the central part of the Minusinsk depression.

The stratigraphy of the sedimentary rocks of the Minusinsk depression may be summarized as follows.

Lower Devonian.—At the base of the sedimentary series of the Minusinsk basin are Lower Devonian formations, which vary lithologically in the different parts of the basin. In the northern part of the basin the Lower Devonian is redresented by red sandstones with intercalations of sandy shales, limestones, and effusive rocks. Asphalt veins occur in the red series.In the southern part of the basin the Lower Devonian is subdivided into three series, as follows: 1. The oldest series consists of red calcareous sandstones with intercalations of dark gray, clayey and bituminous shales. In this region these bituminous shales are the oldest carbonaceous beds. 2. Higher are found gray limestones with *Spirifer nudifer*. 3. The youngest series of the Lower Devonian consists of red sandstones, in which asphalt veins occur.

Middle Devonian: lower part.—In the lower part of the Middle Devonian, a lithologic differentiation is also observed, according to the geographic location in the basin.

In the northern part of the Minusinsk basin the Middle Devonian starts with a series of carbonate rocks, represented by limestones, which at places, are replaced by stratified marls.

In the southern part of the basin, the lower part of the Middle Devonian is represented by a sequence of yellow marls with intercalations of argillaceous and bituminous shales.

Middle Devonian: upper part.—The upper part of the Middle Devonian is represented by a uniform series throughout the Minusinsk basin.

This series with *Spirifer chechiel* consists of sandstones alternating with limestones and argillaceous shales. The major part of these rocks is bituminous. The

upper part of the Middle Devonian, which is bituminous, represents the highest bituminous horizon of the stratigraphic profile of the Minusinsk basin. The bituminous content of this series is stronger than that of the two underlying bituminous series (lower part of the Middle Devonian in the southern part of the Minusinsk basin and the red series of the Lower Devonian in the entire basin.

The bituminous series of the upper part of the Middle Devonian seems to offer more chances of discovering exploitable petroleum. These bituminous rocks are represented by gray compact limestones with sandstone intercalations, as well as intercalations of sandy and argillaceous shales. The beds alternate in the stratigraphic section; argillaceous shales change laterally into limestones; on the contrary sandstones are ordinarily clearly differentiated from the other formations.

Upper Devonian.—The Upper Devonian is represented by a thick series of red rocks.

Carboniferous.—The upper Devonian sediments are overlain by a thick series of sandstones, sandy argillaceous shales, limestones, and marls, all of which belong to the Carboniferous age.

Permian.—Permian sediments, which contain some coal beds, consist of conglomerates, sandstones, and argillaceous shales.

Geophysical exploration work has demonstrated that most of the structures of the Minusinsk basin are strongly affected by numerous dislocations.

It has been possible to discover by means of geophysical methods only one large anticline, situated in the vicinity of the salt works of Abakhansk and which seems not to have been complicated by tectonic movements. The upper beds of this anticline are formed by Upper Devonian sediments; lower beds may be Middle Devonian limestones, within which primary petroleum indications have been observed in the adjacent regions. According to geophysical data this may be a salt dome.

In conclusion, it may be stated that as late as 1941 no commercially exploitable petroleum occurrences have been discovered in the region of Minusinsk; for the time being, the oil-bearing region of the Minusinsk basin is explored only by means of geological methods.

OIL-BEARING REGION OF LAKE BAIKAL

Petroleum indications, concentrated along the eastern and southern borders of Lake Baikal, have been known in this region a long time.

In the region of Lake Baikal the presence of petroleum has been determined under the three forms of liquid oil, ozokerite, and gas.

Petroleum seepages are found in the coastal zone of Lake Baikal and manifest themselves as oil scums on the surface of the water. This oil, which rises from the bottom of the lake, within a zone as far as 800 meters from its coast, sometimes accumulates in such large quantities, that the local residents collect it in barrels. The specific gravity of this oil is 0.970. The presence of these abundant petroleum

seepages, coming from the bottom of the lake, was the reason for attempts to drill test holes from the frozen surface of the lake during the winter season. Thus, during the winter of 1937, two wells on the lake were drilled at a distance of 400 and 1,200 meters from the shore. These wells went through Tertiary formations and penetrated into the underlying gneisses, which were found to be strongly impregnated with petroleum. In the first boring, the oil-bearing zone is found at a depth of 72–102 meters and in the second between 218 and 235 meters. The third well drilled on the lake shore caused, at a depth of 285 meters, an eruption of gas and hot water. However, these wells, which have explored the bottom of the lake, did not succeed to in discovering commercially exploitable petroleum accumulations.

On the other hand, liquid petroleum was found in Quaternary and Tertiary formations and also in the underlying gneisses in test wells drilled on the border of the lake. These test wells determined the presence of one or two zones, containing traces of liquid petroleum, and three or four gas-bearing zones with pressures reaching up to 20 atmospheres. But, even these latter wells, situated on the border of the lake, did not discover petroleum flows of practical importance.

The second variety of petroleum indications is represented by accumulations of ozokerite, either as pockets or strata. The ozokerite is found not only in outcrops, but also in test wells, which explored the bottom and the borders of Lake Baikal.

Finally, the third variety of petroleum indications is represented by emanations of combustible gases, which appear along the eastern border of the lake within an area about 250 kilometers in length.

For a long time the origin of the Baikal petroleum remained unexplained, and it was supposed that the oil-bearing series was formed by the Tertiary sediments lying above the gneisses. Detailed exploration work, which has been carried out since 1930, seems to have proved, on the contrary, that the primary naphthogenic series is represented by Paleozoic sediments. As the result of a *charriage* these naphtogenic sediments of Paleozoic age have been covered by crystalline formations, on which Tertiary and Quaternary sediments were later deposited. Thus, the petroleum indications in the Tertiary and Quaternary sediments are only secondary manifestations and are related to migration of the oil, which came from the fissured gneisses below.

As a consequence of the discovery of this unfavorable genesis of the petroleum in the region of Lake Baikal, further exploration has been abandoned in this region.

The attention of the interested circles is at present concentrated exclusively on the combustible gases, because within the region of Lake Baikal, gas emanations are much more numerous than seepages of liquid petroleum. Indeed, gas indications extend within a very wide zone almost all around the borders of the lake. Along the eastern border gas flows are known on the coast, as well as in the lake itself. The chemical composition of these gases varies considerably from one

place to another. However, it may be stated that on the average these gases have the following composition.

	Percentage
CH_4	65.00–99.00
Lighter hydrocarbons	00.04– 0.35
CO_2	0.23– 2.66
N	4.00–25.00

The yield of combustible gas is frequently considerable; sometimes it exceeds 10,000 cubic meters per day and it is generally characterized by great constancy.

The gases encountered on the northern and western borders of Lake Baikal are distinctly different in chemical composition from those of the eastern border of the lake. The principal part of these gases consists of nitrogen and not of hydrocarbons, and for this reason these gases are more closely related to the gases of the region of the hot springs of Lake Baikal, rather than to the combustible gases of its eastern shore.

The gas indications, discovered before 1941 in the region of Lake Baikal arouse the hope that in the future it will be possible to determine the presence of combustible gas reserves of a size sufficient to supply all the industry of the town of Irkutsk.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 2 (FEBRUARY, 1948), PP. 198-214, 6 FIGS., 1 TABLE

GAS-BEARING STRUCTURES OF SOUTHERN FRANCE[1]

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ABSTRACT

The first drilling in southern France took place in 1919 and centered on seepages in connection with complex salt domes. The attempts were unsuccessful and interest lagged until 1937 when the French Government undertook the investigation of some anticlines in the Petites Pyrenees. The discovery well penetrated a large natural-gas reservoir on July 14, 1939, and since that time the geological and geophysical exploration of the Aquitaine Basin has been vigorously propagated. The report deals chiefly with the geology and production data of the Saint Marcet field. In addition the other exploration activities of the Government are briefly described.

HISTORY OF EXPLORATION

France is formed by rather limited sedimentary Mesozoic and Cenozoic basins that are included in a framework of the Hercynian Chain. In the largest one, the Paris Basin, there are neither gas nor oil seepages, but the basin certainly embraces structures or stratigraphic overlaps and unconformities that may be prospected in the near future. Besides the well known Oligocene Pechelbronn oil field and the small Triassic field at Gabian, southwest of the Central Plateau where the exploration of the Languedoc Basin was commenced, the Aquitaine Basin incorporates the best all-round conditions of deposition and accumulation of oil in a basin.

In the Aquitaine Basin, recently described by Eardley,[3] initial attempts to drill for oil were made after 1919. The early wells were generally drilled near seepages in the southwestern corner of the basin, and the seepages were associated with complex salt domes. No consideration was taken of the stratigraphic or structural conditions. However, one well was located on the anticlinal structure of Audignon. These attempts did not yield any production because of the lack of suitable reservoir rock. In spite of some attractive tar seepages in the region, the negative results caused the oil men to abandon their prospecting. One of the discouraging factors at that time was the difficulty of drilling the very thick sedimentary beds. In spite of favorable reports that Leon Bertrand had furnished a French oil company in 1925, the North Pyrenees basin was forgotten for several years.

In 1937 when the Geological Commission of the Direction des Carburants, presided over by Charles Jacob, was entrusted to draw up a résumé of French oil possibilities, special attention was turned to an investigation of the Aquitaine Basin. On September 2, 1938, Charles Jacob, Léon Bertrand, and the writer

[1] Manuscript received, July 29, 1947.

[2] Chief of geological department of the French Petroleum Institute.

The writer takes this opportunity to thank P. Michel and V. Perebaskine of Saint Gaudens, France, both of whom worked with him in this region for 6 years, and also A. J. Eardley and E. D. Lynton for criticism and suggestions in the preparation of this paper.

[3] A. J. Eardley, "Petroleum Geology of Aquitaine Basin, France," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 9 (September, 1946), pp. 1517-45.

recommended the drilling of the first well on the Saint Marcet anticline in the foothills of the Pyrenees, north of Saint Gaudens (Haute-Garonne). On July 14, 1939, this well penetrated a large natural-gas reservoir and two oil zones at about 5,200 feet; the oil zones produced 150 barrels per day during 4 days, but were plugged back because of technical difficulties.

Following this auspicious discovery, the French State began an extensive drilling program in the Aquitaine Basin. The practical results of this investigation are represented by the following data.

Exploration and exploitation of the area are under the control of the Government, which either acts in cooperation with private interests under the name of Société Nationale des Pétroles d'Aquitaine within the concession of 5,000,000 acres, or operates under the name of Regie Autonome des Pétroles on 500,000 acres of leased land.

GEOLOGY OF AQUITAINE BASIN

REGIONAL RELATIONS

The Aquitaine Basin is in the northern foreland of the Pyrenees Mountains (Fig. 1). From the Aptian stage to the Maestrichtian stage the uplift of the Pyrenees controlled the nature of the deposits and the rate of sedimentation. From the Lower Tertiary to the older rocks, the sedimentary material from the Central Plateau is more and more intermingled with that of the Pyrenees Mountains (Fig. 2).

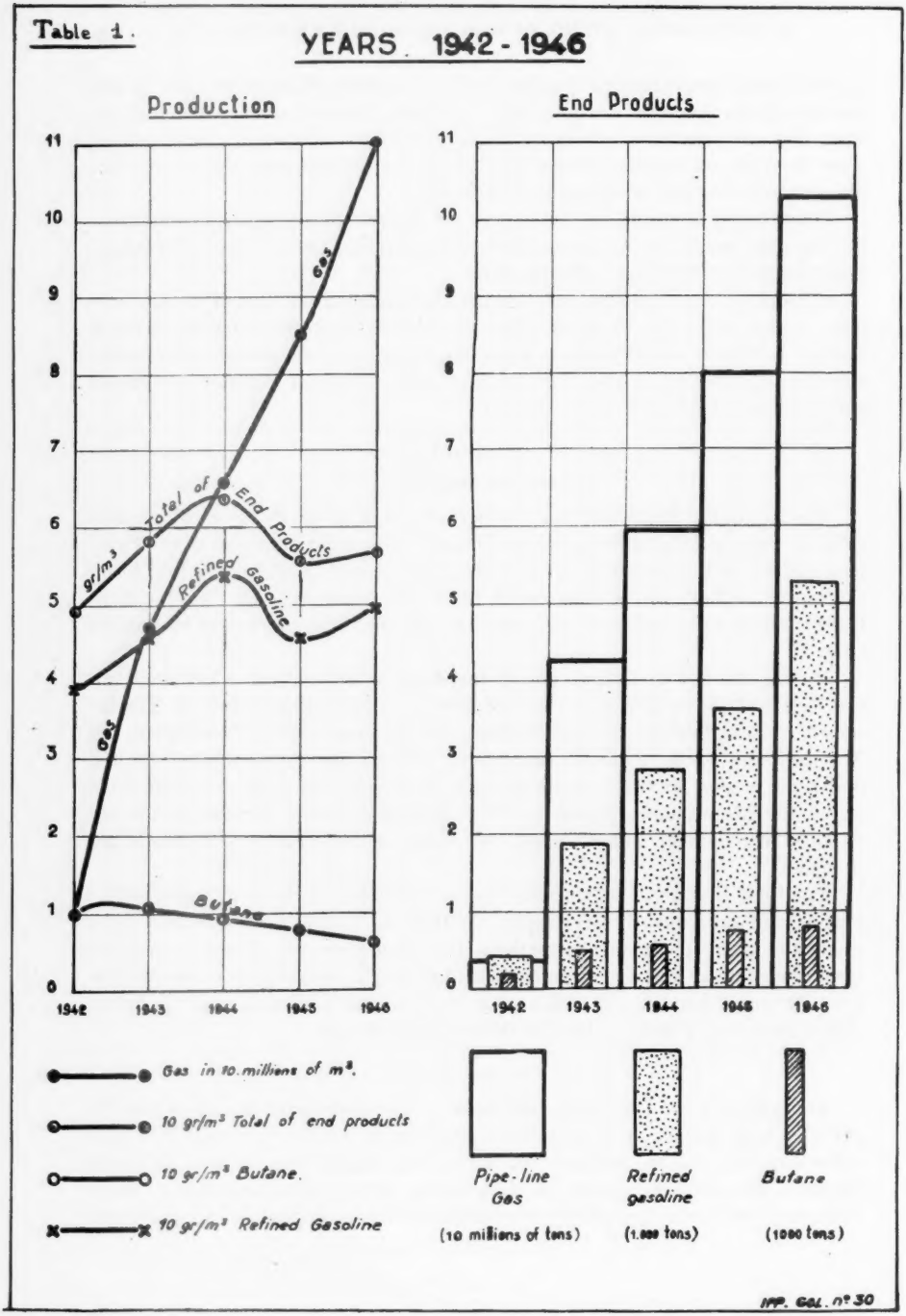
During the middle Eocene period the orogenic movements which built up the Pyrenees Mountains gave rise to folds in the belt of the foreland. The intensity of these folds decreases away from the Pyrenean system. Northward, the Mesozoic and Tertiary rocks progressively rise against the concealed, faulted and rigid borders of the Central Plateau. Eastward, the basin terminates between the Mouthoumet Range and the Montagne Noire. Westward, the old Atlantic embayment widens more and more as the existing shoreline is approached.

The folds that are now concealed in the Aquitaine Basin were truncated by erosion and subsequently overlapped by Miocene marine and lacustrian thick muds and basal (piedmont) formations. Here and there the Miocene cover has been eroded away and a continuous belt of folding is revealed. Such are the Petites Pyrenees, Landes, and Chalosse (near Dax and Bayonne), and the buried ridges that extend westward to the Mouthoumet Range.

STRATIGRAPHY

Fragments of the Hercynian belt make up the basement complex of the Pyrenean Chain. Lying unconformably above this old eroded mountain belt is an epicontinental, marine, sedimentary series, that ranges from Triassic to Upper Jurassic. The Triassic system consists mainly of variegated marls with green volcanic flows, known as ophites. The Liassic series is composed of dolomitic and

TABLE I
PRODUCTION BY YEARS



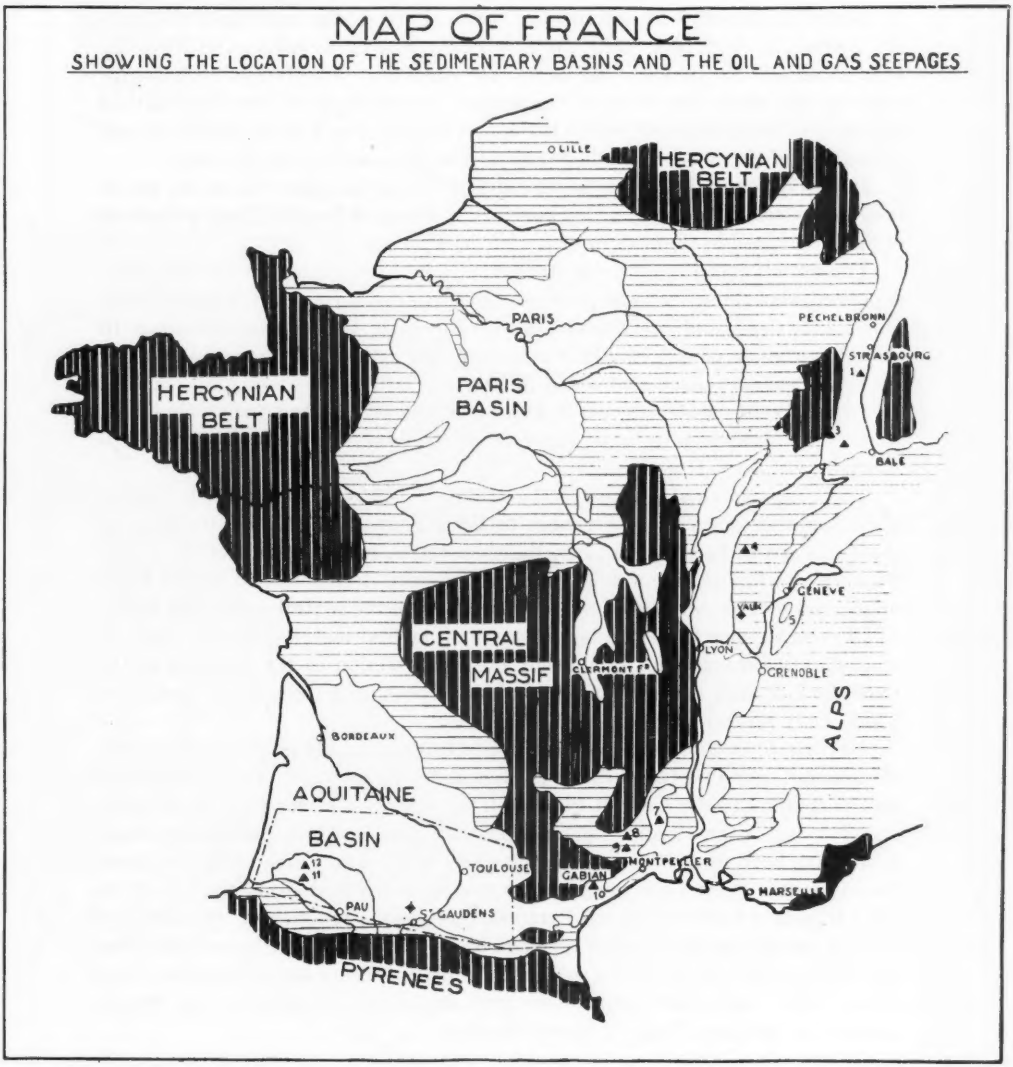


FIG. 1.—Index map of France.

brecciated limestones with interbedded, banded and oölitic limestones conformably overlain by dark blue marly shales with *Harpoceras*, *Gryphaea* and *Rhynchonella*. The middle Jurassic sediments are dolomitic limestones that change laterally into marly limestones in the western part of the Pyrenees. The vertical thickness of this formation, which is the first reservoir rock of the productive oil zone at Saint Marcet, is variable, ranging from 60 to several hundred feet.

In post-Jurassic time, epeirogenic rising of the whole region caused the sea to recede a considerable distance. Pockets or thin layers of bauxitic clays and seams of lignite resulted in the eastern corner of the Pyrenees.

The sea advanced again in the Aptian (Middle Cretaceous) but the sediments deposited were those that presage mountain-building movements. The first sediments were the Aptian reef limestones with *Toucasia*, *Miliola*, and *Orbitolina*. In the Albian stage of the Middle Cretaceous, the sea subsided after depositing thick and uniform black shales and limestones.

In the Petites Pyrenees, we find between the Albian and the Cenomanian stages thick flows of ultra-basic lavas which have been penetrated by the wells at a depth of 8,200 feet.

The Cenomanian stage, also in the Middle Cretaceous, marks the beginning of the Laramic facies of the Pyrenean uplift (Fig. 2). In the basins, the deposits grade upward without a break into the more clastic fine sediments of the flysch. Between the basins, linear folds rose which were deeply eroded before being submerged by the sea. These folds and the uplift of the central axis of the Paleozoic Pyrenean zone furnished large masses of detrital material characteristic of orogenous sedimentation. As a result the basal section in the foreland of the Pyrenees is a thick series of breccia and sandstones, and these grade upward to a fine, shaly typical flysch deposit.

Northward is found the flysch of Upper Cretaceous age grading into an epicontinental, marginal facies which is even now characteristic of the established area pertaining to the Central Plateau. The deposition of the foreland deposits occurred during the Maestrichtian period, and since that time the epicontinental facies have been spread throughout the whole sedimentary area of the Pyrenees. During Upper Cretaceous time, the sea overlapped progressively the top of the axial Paleozoic backbone of the Pyrenees through the junction of the north and south Pyrenean geosynclines. At the end of the Cretaceous, the sea receded from the eastern part of the northern Pyrenean basin leaving large lacustrian areas where white limestones with *Bauxia* were deposited. In contrast, the western part of the foreland is predominantly marine.

During the Tertiary period, marine transgressive and epicontinental conditions spread over the whole Aquitaine Basin, and shallow-water sediments such as the *Lithothamnium*, *Alveolina* and *Miliola* limestones, and sandy shales with *Nummulites* were deposited. The first movements of the Pyrenean diastrophic cycle are recorded by lines of coarse monogenic conglomerates aligned along the

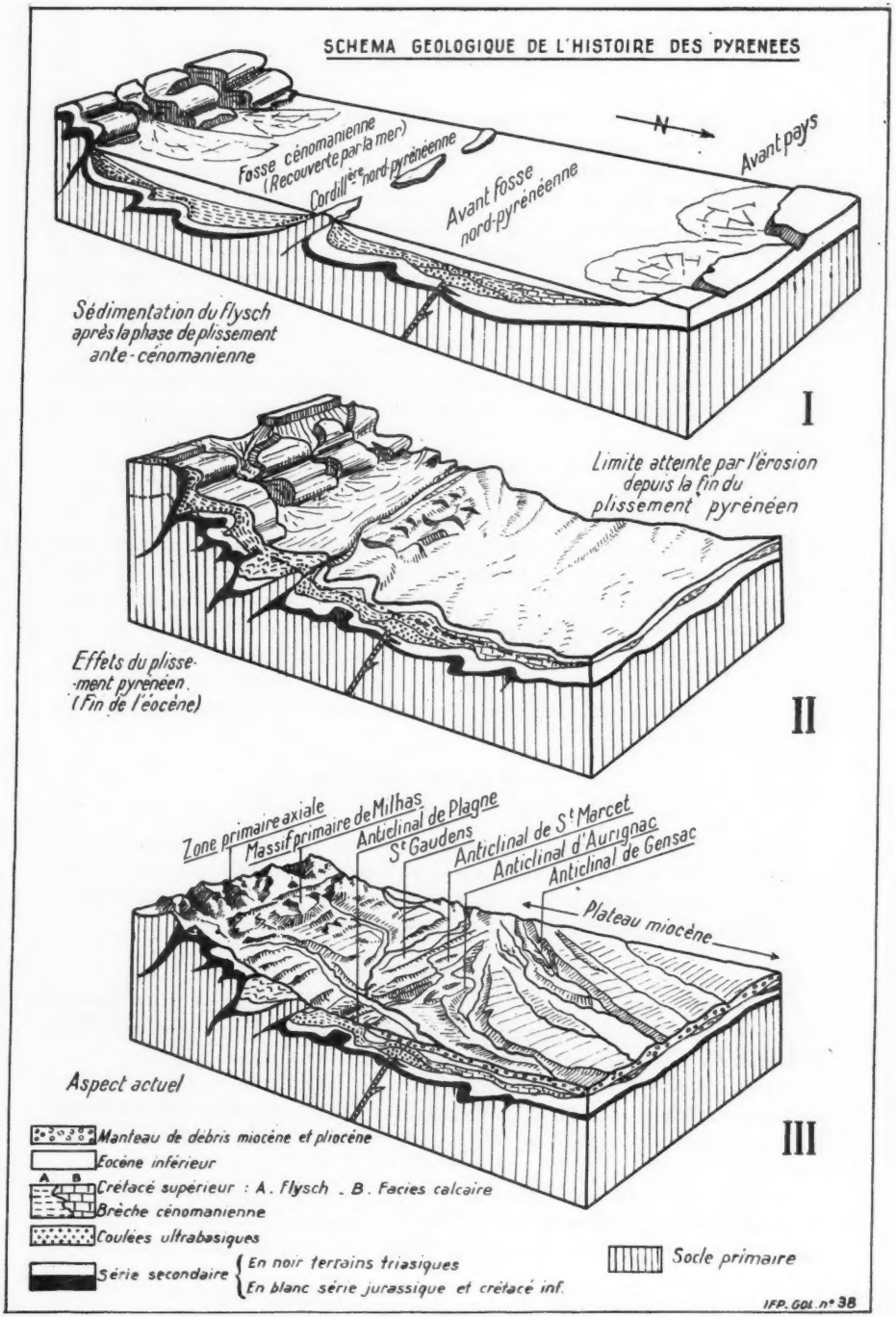


FIG. 2.—Block diagrams illustrating history of Pyrenees and northern basin.

mountain front; these conglomerates of Lutetian and upper Eocene age are involved in the Pyrenean folding. After the uplift of the chain, a leveling cycle began providing the Aquitaine Basin with abundant conglomerates, sands, and clays. During the Miocene period, the shoreline remained on the western side; the main part of the Aquitaine Basin was filled by fresh-water molasse, coarse widespread piedmont conglomerates and clastics. These materials were derived from the recent Pyrenean uplift. The sediments lie horizontally on the folded Eocene and Cretaceous basement.

TECTONIC FEATURES

In the Pyrenees strong folding and faulting followed by erosion have resulted in sharply infolded synclines in a complex manner between cores of Paleozoic basement.

Locally, one can see an overthrust of limited magnitude on the north and the south fronts of the mountain chain. The foothills limiting the front of the range originated from the earlier orogenic cycle, and developed ultimately into the frontal overthrust. It must be admitted that folds such as diapiric structures and series of brachy-anticlines were developed during the Pyrenean orogeny, but these decrease gradually northward. In the Petites Pyrenees foothills a very gently dipping series of folds has been exposed by the action of erosion, but other structures are still buried under the blanket of Miocene and piedmont formations. Therefore, the buried folds were studied first by reconnaissance geophysical methods (gravimetric and earth potential), and these were followed by the more detailed seismic.

SAINT MARCET GAS-FIELD

LOCATION

The Saint Marcet anticlinal structure was the first to be developed in the Aquitaine Basin. It is located in the Petites Pyrenees foothills, 9.25 miles north of Saint Gaudens and 44 miles southwest of Toulouse (Fig. 3). The extent of the structure is about 75,000 acres, and the axis is about 14 miles long.

HISTORY

As indicated previously, the discovery well (Louis Pineau well) was located 1,000 feet south of the axis on geological evidence alone. There were no outside indications of oil or gas seepages on the Saint Marcet anticline.

During World War II, 14 other wells were drilled. One of them produced oil and gas condensate under the same conditions as the discovery well; the others were gas-condensate wells. Two of them were dry because of the non-porosity of the rock.

To date, the total production of the field has been 15,000 barrels. This oil is being produced from only one of three structural highs along the anticlinal axis. The second high, the Proupiary, east of the first, has been tested by two

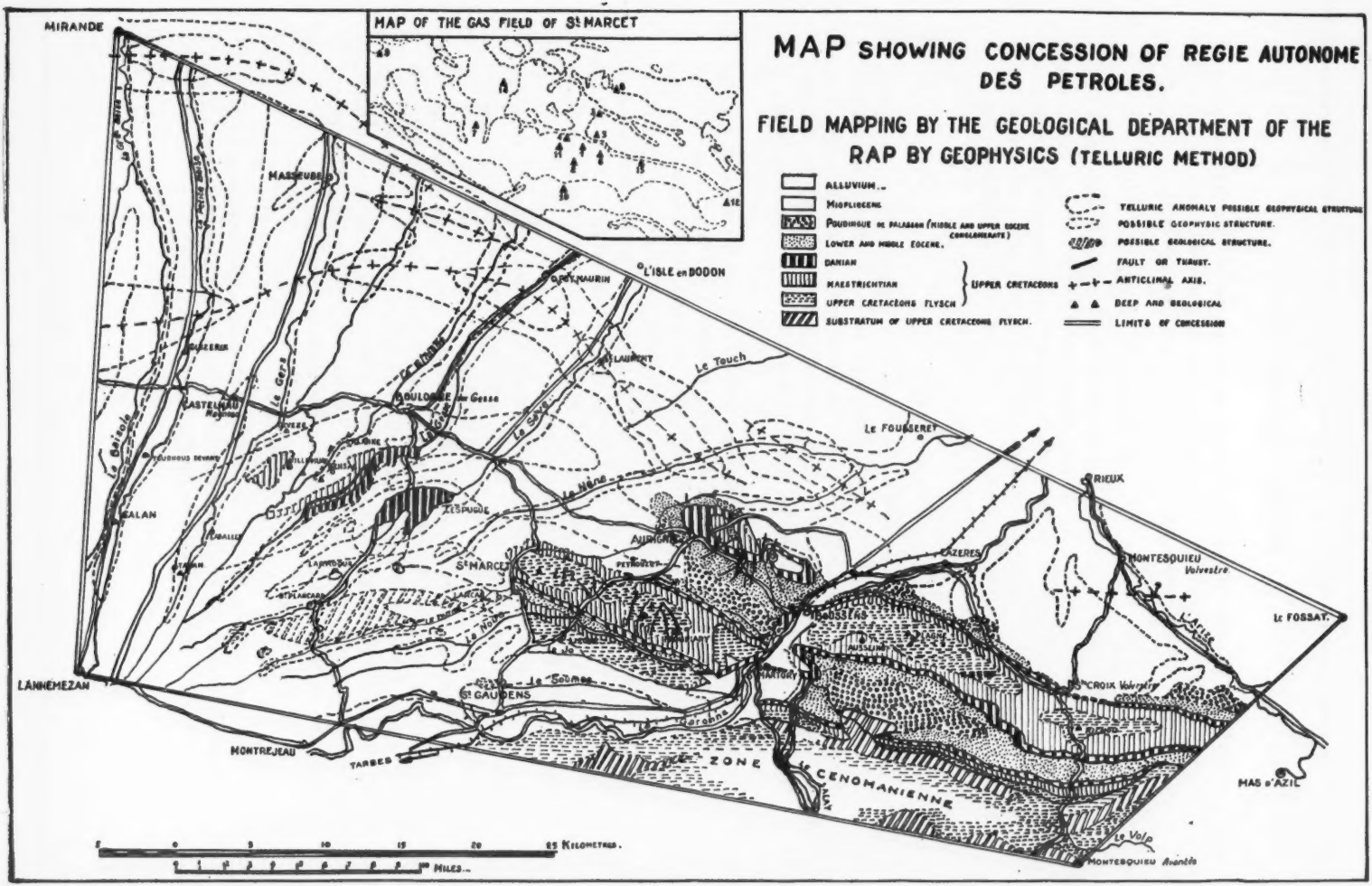


FIG. 3.—Geologic map of St. Marcet and related gas fields.

wells. One of them showed gas condensate, while the other one is still being drilled. The third one, the Saint Martory extension, has been tested to date by one well located on the east closure; this test has also struck a gas reservoir.

GEOLOGY

The Saint Marcet anticline is marked on the surface by a core of Upper Cretaceous flysch surrounded by Maestrichtian limestones forming a cuesta-like landscape on the south flank. On the north flank, the overlapping Miocene has partly capped this limestone formation. The dips of both flanks range from 25° to 30°. Minor faults cross the crest of the east-west trending anticline (Fig. 4). An electrical log of the discovery well is shown in Figure 5.

STRATIGRAPHY

The wells penetrated the flysch which consists of massive shales interbedded with numerous fine lenticular sandy limestones having a vertical thickness of 3,960 to 6,940 feet or more. The age of this formation has been determined by extensive micropaleontological studies under the direction of M. Perebaskine, and ranges from Cenomanian to Maestrichtian age without apparent breaks in the sedimentation.

At the base of the flysch there is an intraformational breccia with nodular limestone pebbles imbedded in a black shaly matrix. This formation begins with a polygenic breccia with dolomitic and clastic elements. The thickness of these rocks which constitute the first reservoir rocks of the gas condensate ranges from 495 to 660 feet. The variation in the thickness can be explained by the irregularities of the pre-Cenomanian topographic features of the structure.

Due to an earlier erosion a breccia lies unconformably on formations ranging from Middle Jurassic to Lower Jurassic.

On the top of the structure the wells penetrate banded oölitic and dolomitic limestones of Lower Liasic age. Then, they cross variegated shales with gypsum and anhydrite of Keuper age. The basement has never been reached.

On the flanks, which are greatly disturbed, the Cenomanian breccia lies on the Jurassic dolomitic limestones. Between these beds and the Lower Liassic limestones, there are carbonaceous shales with *Gryphaea* and *Rhynchonella* belonging to the Aalenian stage, and shales with cherty limestones containing *Pentacrinus* of Charmouthian age. The Lower Lias and the Keuper are also of this type, as substantiated by wells drilled on the structural high.

STRUCTURE

The cross section through the Saint Marcet anticline reveals striking discordance between the gentle and regular contours of the anticline of the surface and the highly disturbed diapiric conditions at depth (Fig. 6).

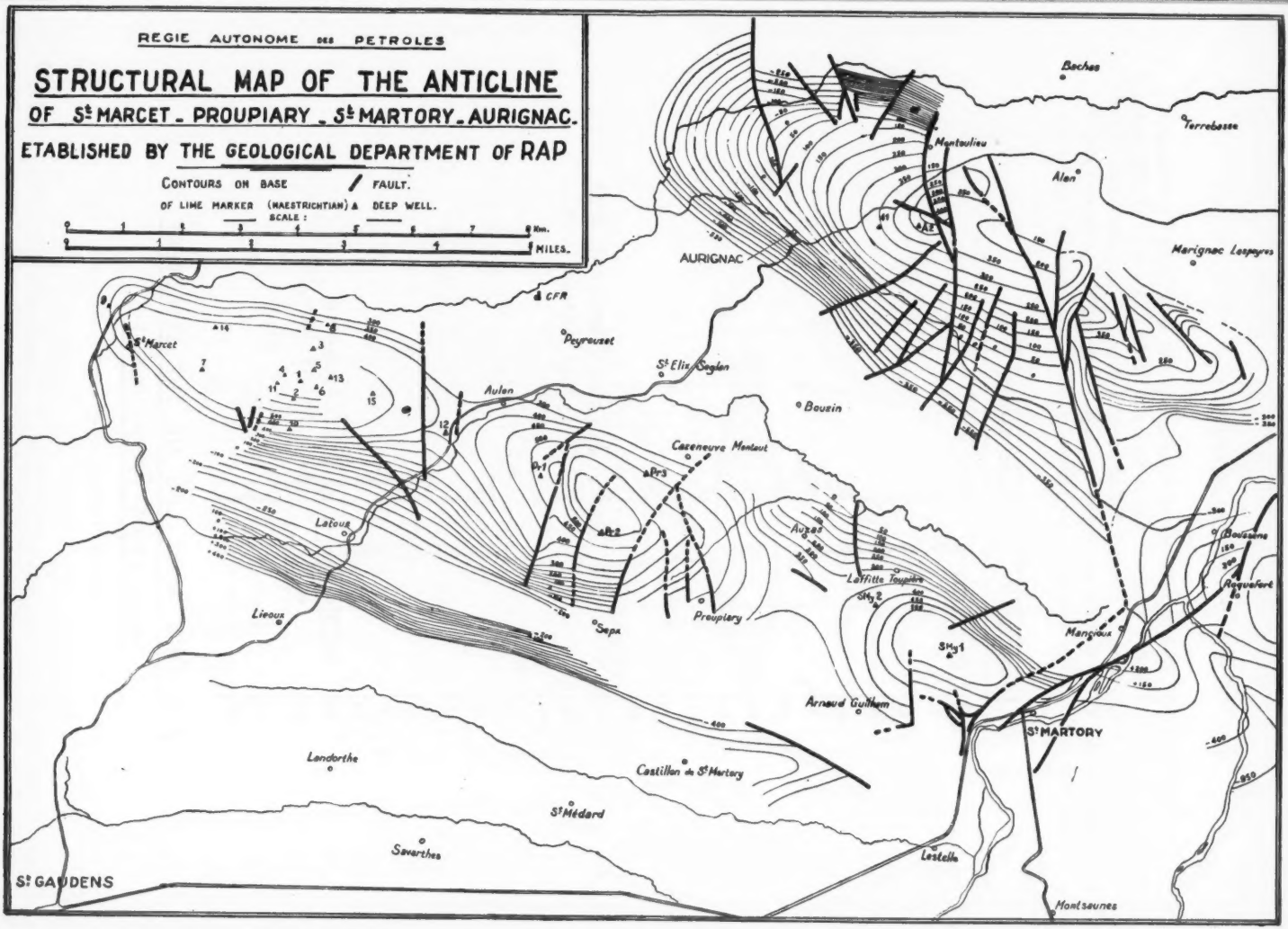
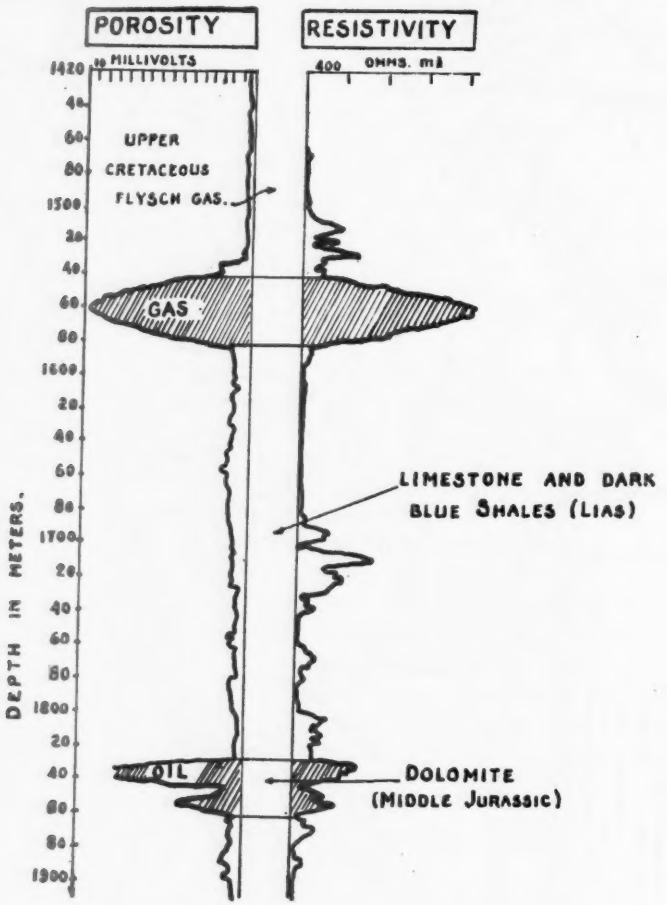


FIG. 4.—Structure map of St. Marcet, Proupiary, St. Martory, and Aurignac.

Characteristic of this deep-seated structure is the association of a diapiric anticline with reverse, diagonal shears on both flanks. This type of fold was formed in two phases. In the first during pre-Cenomanian age, there was an uplift followed by erosion on the top of the fold. Then, secondly, this embryonic fold was buried under a considerable mass of plastic sediments which thicken in



ELECTRIC WELL LOG OF THE DISCOVERY WELL LOUIS PINEAU. (SM1)

FIG. 5.—Electric well log of discovery well Louis Pineau.

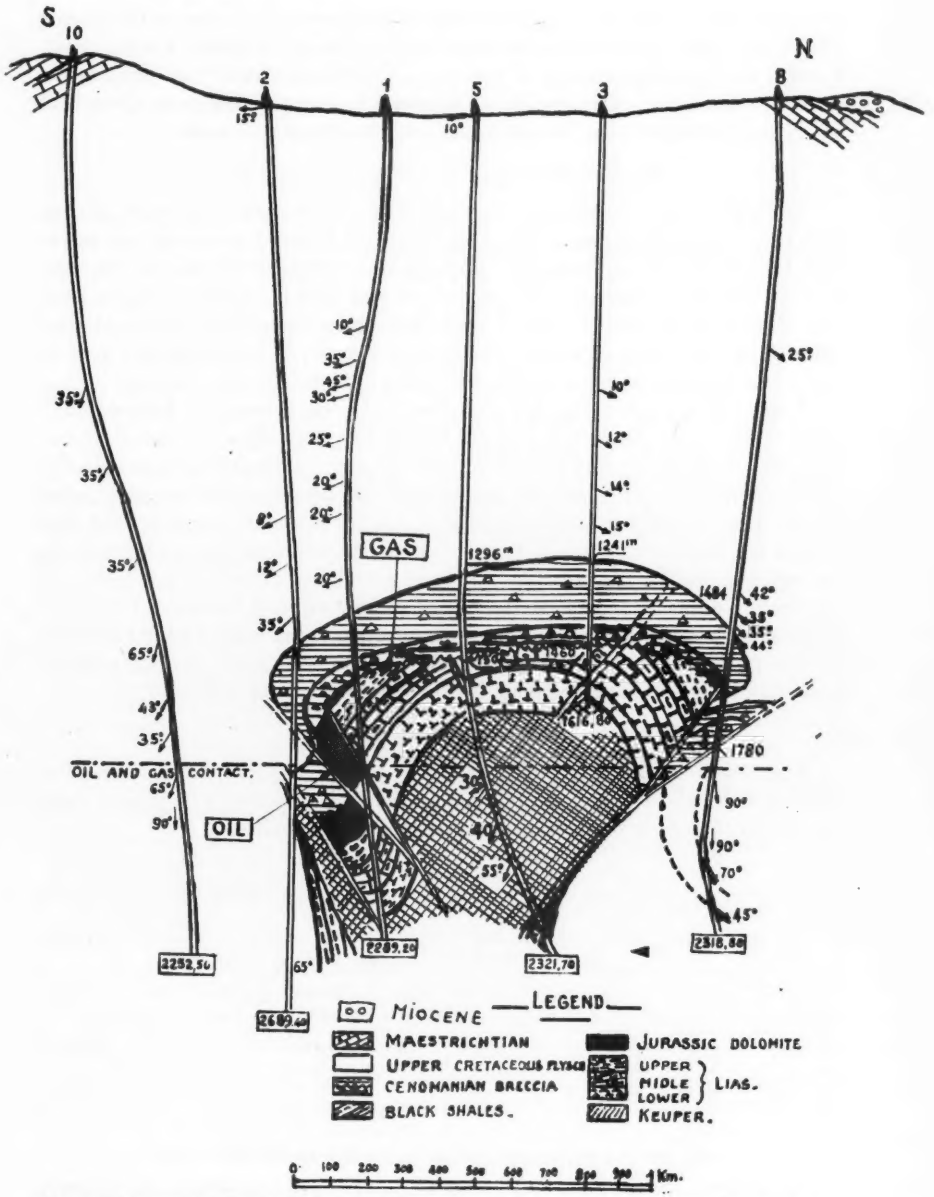


FIG. 6.—Cross section of St. Marcet anticline as interpreted by D. Schneegans and P. Michel.

the adjacent downwarping synclines. During the diastrophic phase of the middle Eocene the uplift continued under the diapiric action of the plastic Keuper mass. Finally, due to the squeezing of the two adjacent synclines, the compressive stresses have developed in the flanks diagonal faults very similar to those that have been described in the Turner Valley oil field, Alberta, Canada.

CHARACTERISTIC FEATURES OF OIL AND GAS POOL

Because of the Cenomanian unconformity the structure of Saint Marcet shows two layers of geology. The upper layer of Upper Cretaceous age begins with breccia and intraformational conglomerates which constitute the reservoir rock of the gas condensate. The porosity of this zone is variable, ranging from 2 to 18 per cent. It reaches a higher ratio even where the pebbles and the binding material are dolomitic or clastic. On the other hand, in the monogenic breccia of the roof the ratio is generally low, excepting in highly disturbed zones.

Below the unconformity, the next reservoir rock consists of Jurassic dolomites which vary considerably in thickness. The dolomites are vacuolar, saccharoidal, and sandy from place to place but everywhere highly fissured. The average porosity is 10 per cent but porosities of 18–20 per cent are not exceptional.

The bottom of the gas cap is located at a depth of about 6,040 feet. The high part of the structure, which is broad and regular, contains gas condensate. On the other hand, the flanks of the structure are highly disturbed and makes oil exploration difficult. Indeed, to date, very steeply dipping dolomites have been found as oil-bearing beds at depths ranging from 6,040 to 6,400 feet in two wells.

The unconformity surface connects the two reservoir rocks, and the pressure of the gas wells is about 2,000 pounds per square inch at the well head.

GAS-PRODUCTION DATA

There are ten productive wells, each able to furnish about 780,000 cubic feet per day. On May 1, 1947, the production reached a total of 552,500,000 cubic feet of gas. The daily production of oil reaches 772,600 gallons.

CHEMICAL ANALYSIS OF GAS

	C_2+N_2	C_2	C_3	$N\,C_4$ *and* *iso-*C_4	C_5+ *sup. h.*	H_2O	CO_2	*Density*
Gas from well	91.4	4.2	2.4	0.8	1.2	Traces 1.5 gc/u. meter	0.1	0.638
Wet gas	92.4	4.2	2.2	0.6	0.6	Traces		0.612
Dry gas	94.45	4.0	1.2	0.27	0.08	Traces		0.593

OIL PRODUCTION AND CHEMICAL ANALYSIS OF CRUDE OIL

Well SM 11 gives a daily production of about 660 to 770 gallons of a paraffinic oil with a gas-oil ratio of 29.971 cubic feet per barrel.

CHEMICAL ANALYSIS OF OIL

Gravity A.P.I.	*Gasoline*	*Kerosene*	*Gas-Oil*	*Residue*	*Losses*
31	22.5%	5.68%	11.40%	59.56%	0.80%

The bottom waters are variable in concentration and in composition. The more concentrated waters of well SM 5 (the salinity of which is 142.8 grams per liter) are of the sodium chloride type with bromide and iodide; the sulphuric ratio is low (0.9). The bottom waters of the other wells are of the same type but less concentrated.

The waters of SM 7 SM 11 are exceptions and are of the sodium carbonate type with light salinity (4.3 grams per liter). The waters show a base-exchange ratio and a high carbonate content which is possibly the result of reduction of sulphates and oxidation of hydrocarbons.

These chemical characteristics could be explained by a process of modification of the deep meteoric waters by their mixing with fossil waters, and both leaching the enclosing rocks, especially the Triassic salt-bearing sediments.

The removal of the waters is made through fissured and disturbed zones of the dolomites and limestones. Therefore, the equilibrium between oil and water is scarce and we can not affirm whether the field produces under volumetric or hydraulic conditions. Vertical rising of the water table has not been observed during the exploitation.

DRILLING AND OPERATING METHODS

The casing program adopted in the Saint Marcet gas field is as follows.

13⅜-inch surface casing at 200 or 300 meters for water shut-offs
9-inch casing at about 1,300 meters for lining the flysch marls (a porous formation having a mud absorbing effect if well put under pressure)
6⅝-inch casing at the base of the Cenomanian breccia, with possibility of running a liner in the hole for eventual production in the Jurassic dolomite found in deeper zone

Production tests in the Cenomanian breccia have been carried out. The interesting zones, starting from the bottom are the following.

1. Cemented 6⅝-inch casing perforated by stages, with Schlumberger perforating gun
2. Well placed on production
   a. By bailing the first holes
   b. By injecting gas under pressure from other wells to remove the mud and allow the well to flow gas

OTHER STRUCTURES OF PETITES PYRENEES

The development of the Saint Marcet structure is now being continued by the drilling of the structural highs of Proupiary and Saint Martory (Fig. 4).

In the Proupiary structure the gas condensate has been found in Jurassic dolomites at a depth of 6,322 feet. Two other wells are now being drilled on the southern and northern flanks of the structure. The first well located on the western dome-shaped end of the Saint Martory high showed a trace of gas in the Cenomanian breccia.

The Saint Martory anticline is continued on the eastern side of the Garonne valley by two large overturned folds. The first one, the axis of which is 10 miles

long, is named the Palgne anticline. The north flank dips from 45° to 90° southward; the south flank from 30° to 45°. The flysch core is deeply cut out by erosion and surrounded by a cuesta-like escarpment of Maestrichtian calcareous sandstone.

The first well which was drilled on the south flank of the anticline found a strong gas showing with salt water. This well did not find favorable reservoir rocks in the flysch formation and was abandoned at a depth of 6,557 feet without finding the substratum of the flysch. The head pressure was 140 kilograms; the bore hole was full of gas and water.

South of the first well another deep well is now being drilled in order to find the substratum of the flysch formation by crossing the axial plane.

Eastward, this anticline is extended by the Richou anticline, the northern flank of which dips 60°–80° northward and the southern flank 25°–30° southward.

A deep well is now being drilled on the south flank through the flysch formation in order to find the substratum. Gas showings have been noted during the drilling operations.

North of the Saint Marcet anticline there is another fold, the top of which is 900 feet lower than the former one. This dome-shaped Aurignac anticline is cut by numerous transverse and diagonal faults. These faults divide the fold into three highs. The first well is located on the south flank of the western high, which transversely is asymmetric at the surface. At the depth of 7,590 feet, the well was still in the flysch formation. Here, at the base of the flysch is a hard conglomeratic, thin-bedded, sandstone series without oil or gas. Below this is an ultra-basic lava sheet which has been drilled to the depth of 8,927 feet. The well showed some traces of dead oil in the flysch formation. Two other wells are still being drilled.

The structure of Gensac is partly buried under the overlapping Miocene formation. The first well which was drilled on the axis of the anticline penetrated 3,497 feet of dark blue shales of Maestrichtian and Campanian age lying on a tremendous mass of sandstone. From 1,640 to 8,310 feet, the well penetrated ultra-basic buried volcanoes, probably of Aptian age. The well was stopped at a depth of 10,000 feet in calcareous shales of Albian or Aptian age. Tar sands were found in the upper part of the Senonian sandstones, and traces of light oil were observed in the Albian or Aptian limestones, but because of lack of porosity the rock was unable to produce.

Two other wells were drilled on the Gensac anticline. One of them was located on a second high according to geophysical data. These two wells reached the Senonian sandstones and struck only salt water. These unfavorable results led to the location of prospect wells in the direction of the pinching-out of the porosity belt disclosed by the first Gensac well. This explains the important geophysical survey of the northern corner of the lease. The joint use of seismic and earth-potential methods led to the identification of trains of buried anticlines

slightly reflected in the Miocene blanket. The Puymaurin well No. 1, still being drilled, has reached a depth of 12,068 feet. Under the reduced Eocene and Upper Cretaceous series, the well reached a thick lower formation with *Orbitolina* limestones and other sediments of epicontinental type. A well, located near Saint Medard, north of Puymaurin, drilled by SNPA (Societé Nationale des Pétroles d'Aquitaine), reached the same series.

In the eastern corner of the Aquitaine Basin we see the prolongation of the folds of the Pyrenees foothills. The Dreuilhe anticline which is located near the little town of Lavelanet is a very well marked asymmetric anticline. Three holes have been drilled near the axis of the structure, but only small gas showings were found. This train of anticlinal folds rises to form the southern range of the Mouthoumet Paleozoic Mountains.

Northward, we find a buried ridge which is in connection with the northern range of the same mountains. Two dry holes have reached the Paleozoic basement under a blanket of Upper Cretaceous detrital formations, at depths ranging from 3,300 to 4,950 feet. The other structural trends of this part have been prospected by geophysical surveys using a combination of earth-potential and gravimetric methods.

In the southwestern corner intensive structural work has been done by the geologists of the SNPA in order to localize structural closure in highly complex diapiric structures and other kinds of disturbed folds. These structures are partly hidden on the surface by recent Mio-Pliocene deposits and surface surveying must be supplemented by geophysical methods such as electrical, gravimetrical, and seismic operations. The stratigraphic patterns of these regions are being carefully studied by surface surveys and drilling in order to find suitable reservoir rocks. The structures are included in the deepest part of the sub-Pyrenean basin. The porosity conditions in the central part of the basin do not seem theoretically suitable, and therefore, stratigraphic traps may be found on the northern margin which is hidden under Miocene and Pliocene sediments.

Between the Petites Pyrenees and the structures of the southwestern corner of the Aquitaine Basin, geophysical exploration has recorded two anomalies which may possibly correspond with structural anticlinal features.

A deep well is still being drilled on the telluric anomaly of Garlin, north of Tarbes; and there have been heavy asphaltic showings in the Albian and Aptian limestones. But reservoir rocks, such as Jurassic dolomites, have not been found between the Cretaceous rocks and Triassic diapiric (?) cores of the structure. The structure of Audignon which was formerly drilled without success in 1929, is being drilled again in order to discover the nature of the substratum of the thick series of Albian and Aptian marly limestones. The depth of that bore hole is now more than 3,300 feet. A third deep well is located on the western flank of the Bastenne-Guajacq salt-dome well, known by the prolific overlapping tar sands encountered on the surface on its northern rim.

CONCLUSION

Wildcat drilling has been done in the southwestern corner of the Aquitaine Basin where numerous seepages, mostly of dead oil, occur. The failure of all these wells discouraged exploration after 1929, until 1937 when a new drilling program was established, following a better understanding of structural and sedimentary processes in the central foothills of the Petites Pyrenees. These explorations were sponsored by the Government and have now led to the discovery of a big gas field located 10 miles north of Saint Gaudens. Besides the gas-condensate production, small production of paraffine-base oil has been obtained from porous dolomites.

Three pipe lines have been built, the first reaching Toulouse; the second, Tarbes; and the third Saint Girons and Pamiers.

Prospecting is stilll going on in order to find the favorable conditions for oil in the geological province of the Aquitaine Basin. The coordination of geological and geophysical data seems to show that valuable prospects may become definite promises of discoveries in a near future.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 2 (FEBRUARY, 1948), PP. 215-227, 1 FIG., 1 TABLE

OUTLINE OF SEDIMENTATION IN MARACAIBO BASIN, VENEZUELA[1]

H. P. SCHAUB[2]
Havana, Cuba

INTRODUCTION

The writer has read with great interest the paper by F. A. Sutton[3] on the geology of the Maracaibo basin, as he has worked in the Maracaibo basin as exploration geologist since 1938. The great value of the paper lies in the presentation of many geological and paleontological data which have remained in private files for years without being published.

A shortcoming, on the other hand, is seen in the fact that some of these data are not sufficiently discussed and that many statements, for example, those regarding correlations, are made without supporting evidence. This gives the impression that few problems remain to be solved, which is certainly not the fact.

Sutton's paper is essentially a work of compilation. Probably he had to rely in many instances on information of varying value, as he himself mentions in the chapter on producing structures. Many additions and amendments could therefore be made. It is, however, not the writer's intention to go into details, but rather to discuss the general outlines of sedimentation in the Maracaibo basin and to point out some of the difficulties hampering correlation.

Knowledge of the geology of the basin is now, after nearly 40 years of exploration, still sketchy. Geological work in this area is very difficult due to a number of circumstances. As such should be mentioned the great extension of the area, the difficulty of access in many parts of the basin, the scarcity of outcrops and of complete, comparable surface sections, due to tropical weathering and forest cover, the absence of fossils in many, and of recognizable, well defined fossil horizons in most formations, and last but not least the fact that little is known of the stratigraphic developments over an extensive area in the center of the basin. Although many exploration wells have been drilled in the interior of the basin, only a small part of the stratigraphical section in general has been pierced, and an area of at least 25,000 square kilometers is a blank space as far as facies developments in the Eocene and Cretaceous are concerned. Most correlations across the Maracaibo basin are therefore to be considered as tentative and subject to change. Under these circumstances it is only natural that geologists still disagree on many points.

[1] Manuscript received, September 19, 1947. Published by permission of the Bataafsche Petroleum Mij., Carel van Bylandtlaan 30, The Hague, Netherlands.

[2] Geologist, formerly with the Caribbean Petroleum Company, Maracaibo, Venezuela, now with Cia. Petrolera La Estrella de Cuba, Havana, Cuba. The writer wishes to thank the Bataafsche Petroleum Mij., The Hague, for the permission to publish this paper. He is grateful to L. Kehrer and associates in Venezuela and to F. G. Keyzer, Havana, for reading of the manuscript and for many valuable suggestions.

[3] F. A. Sutton, "Geology of Maracaibo Basin, Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 10 (October, 1946), pp. 1621–1741.

PRE-CRETACEOUS

Little need be said on the stratigraphy of the pre-Cretaceous, as present knowledge is summed up very well by Sutton. Obviously, much work remains to be done on the metamorphic and igneous rocks, their relations to each other and to the various orogenic movements. The oil geologist is little concerned with the cores of the Mérida Andes and the Perijá Mountains and thus these are visited on hurried excursions only where they are easily accessible. The core of the Perijá Mountains is practically unknown. Yet, a careful study of the interior of the mountain ranges would certainly add much to a better understanding of the early history and the development of the Maracaibo basin.

CRETACEOUS

Although the Cretaceous of western Venezuela is rather well known, there are still several problems to be solved. Thus, the age of the transgression at the base of the Cretaceous sequence, its progress, and the direction from which it came remain to be determined. This is difficult because the beds just above the unconformity consist mostly of non-fossiliferous sandstones and conglomerates. The earliest marine faunas found in western Venezuela are Upper Aptian to lower Albian in age. *Orbitolina concava* var. *texana* occurs in the state of Trujillo in limestones little above the unconformity which reached this area probably in Upper Aptian time. In the Machiques area as well as in the state of Táchira, however, the sedimentation may have started earlier, as indicated by the presence of *Weichselia* in the Tomón formation of Táchira.[4]

Lower Cretaceous with rich marine faunas is known from the Cordillera Oriental of Colombia. The transgression may have come from the south-southwest and reached the southwestern parts of the Maracaibo basin first, perhaps following geosynclinal troughs coinciding with the present mountain systems. This question, however, can be solved only by a regional study including Colombia as well as western Venezuela.

Correlation within the Cretaceous of the Maracaibo basin is still tentative as pointed out by Sutton. This is mainly because the boundaries of most formations are transitional and thus rather arbitrary and because well defined fossil horizons have not yet been found throughout the basin. To quote Sutton, the lithologically defined formations may "ascend the time scale and cross age boundaries."[5] Therefore, it is of importance that at least one sharp boundary can be recognized which can be traced consistently throughout the Maracaibo basin. It separates the La Luna from the Colón formation and marks the strong facies change from the bituminous, slaty limestones of the La Luna formation to the foraminiferal clays of the Cólon formation. A thin bed of glauconite-sandy limestone or of sandstone, which in many places contains glauconite and in a few places phos-

[4] H. D. Hedberg, "Mesozoic Stratigraphy of Northern South America," *Proc. 8th Amer. Sci. Congress 1940*, Vol. 4 (Washington, 1942), pp. 195–227.

[5] F. A. Sutton, *op. cit.*, p. 1641.

phoritic pebbles, forms the base of the Colón formation. It has been observed in the La Paz and Tetones fields, in the northern Sierra de Perijá, in the fields of the Barco Concession of Colombia, in Táchira, and along the northern foothills of the Andes. In the Mara-Maracaibo districts it is overlain by 20 meters of gray marly limestone which contains the same foraminiferal fauna as the Colón formation and must be assigned to the latter.

An unconformity can not be observed at this contact. Only at one place near the village of Torondoy (state of Mérida, approximately 50 kilometers north-northeast of the town of Mérida) did the writer see small solution cavities in the uppermost bed of the La Luna formation into which the basal sand of the Colón formation entered. This and the presence of glauconite point to a strong reduction, possibly a short interruption of sedimentation. It is probable that such a change was due to an event of regional extension, occurring at the same time everywhere throughout western Venezuela. It provides therefore reliable correlation in this area and perhaps into adjacent regions.

The relation between Cretaceous and Tertiary is not well established. In the southwestern part of the Maracaibo basin there is not much reason to assume a gap in the sequence, as there is a transition between the uppermost Cretaceous and the lowermost Tertiary formations.[6] The absence of Paleocene fossils can not be used as an argument against such a transition, as Tertiary fossils are rare throughout this part of the basin.

The absence of the Mito Juan formation in the state of Trujillo, however, may point to a gap in this area and the extension of this formation should, therefore, be studied carefully.

TERTIARY

Three facies provinces can generally be recognized in the Tertiary of the Maracaibo basin: the Bolivar province, the Colón province, and the Mara province, according to the districts of the state of Zulia in which good surface sections of the three facies types can be observed. It is obvious that there are no sharp boundaries between them and that minor facies changes occur inside the provinces. Knowledge of these provinces is a pre-requisite for the discussion of the Eocene correlation in the Maracaibo basin (Fig. 1).

BOLIVAR PROVINCE

The Bolivar province covers the area east, southeast, and south of Lake Maracaibo, namely, the districts of Miranda, Bolivar, and Sucre of the state of Zulia and the northern slope of the Merida Andes in the state of Trujillo and in eastern Merida. The characteristics of the Tertiary in this province are a predominantly marine facies of the upper Eocene (Orbitoid limestones, shales with rich microfaunas) and the occurrence of orogenic movements marked by strong

[6] F. B. Notestein, C. W. Hubman, and J. W. Bowler, "Geology of the Barco Concession, Republic of Colombia, South America," *Bull. Geol. Soc. America*, Vol. 55, No. 10 (October, 1944).

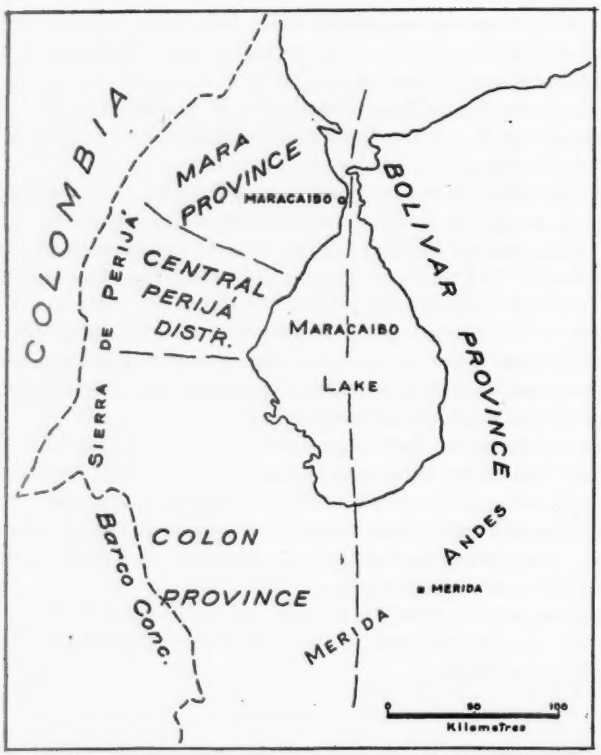


FIG. 1.—Sketch of Maracaibo basin showing approximate extension of Tertiary facies provinces.

unconformities which have been observed at the base of the upper Eocene Paloma Alta formation, at the base of the post-Eocene sediments and in the Miocene.

In this area Sutton differentiates the following formations from top to bottom.

Formation	
El Milagro	Pleistocene
La Puerta Lagunillas La Rosa	Miocene
Icotea	Oligocene
Ambrosio—Churuguarita Las Flores—upper Paují Potreritos—lower Paují Misoa Trujillo	Eocene
Guasare	Paleocene

Nothing need be said about the post-Eocene formations which are well known from the many well sections of the Bolivar field. In the Eocene, Sutton places his Potreritos formation above the Misoa formation and correlates it with Tash's[7] transition zone of the Mene Grande field, omitting, however, to give any proof for his assertion. The reason for this correlation can be found in the description of the Misoa formation[8] where he states that "the Misoa . . . is productive on the Pueblo Viejo structure in the southern part of the District of Bolivar." Obviously, this refers to the so-called Pueblo Viejo Main sandstone,[9] a quartzitic sandstone body very similar to, but not identical with, the sandstones in the upper part of the Misoa formation. This sandstone body is in fact situated below, or in the lower part of, the Potreritos formation. However, there is also reason to assume that the Pueblo Viejo Main sandstone is situated more than 1,000 meters below the top of the Misoa formation as defined by Sutton, although still within it. This seems proved by the occurrence of a typical microfauna in shales above the Pueblo Viejo Main sandstone which has also been found in the lower part of the Misoa formation over a wide area east and north of the Mene Grande field.

Based on these indications, we can tentatively correlate the Potreritos formation with the upper part of Sutton's Misoa formation. This checks well with Sutton's statement that the Potreritos is the least fossiliferous of the Eocene formations of the Bolivar field with the exception of the Misoa. The few small Foraminifera of the Potreritos occur also in the upper part of the Misoa formation. The difference in facies and heavy-mineral content might be considered as an argument against the proposed correlation, but on the other hand, if Sutton's correlations with his "Lower Paují" of Mene Grande were correct, a reduction in thickness from 1,371 meters in the Bolivar field to, say, 150 meters in Mene Grande would have to be assumed, and this would represent just as much of a facies change. Finally, we should examine whether there is any difference in age between the formations. Sutton places both in the upper Eocene. Fossil evidence is very poor in both cases, but it certainly does not contradict the correlation of the two formations.

COLÓN PROVINCE

The Colón province covers the Colón district and the southern Perijá district of the state of Zulia, the state of Táchira, and extends along the northern slope of the Merida Andes into the state of Mérida. It also covers the neighboring area of Colombia where the sequence was described by Notestein *et al.*[10] from the Barco concession. The facies is mainly brackish-terrigenous. Macrofossils are rare and indicate brackish conditions, the microfaunas are poor and consist only

[7] G. E. Tash, "Stratigraphy and Paleontology of Mene Grande and Its Surroundings," *Bol. Geol. y Min.*, Vol. 1, Nos. 2–4 (Caracas, 1937).

[8] C. A. Sutton *op. cit.*, p. 1668.

[9] Local name used in the Pueblo Viejo field.

[10] F. B. Notestein, C. W. Hubman, and J. W. Bowler, *op. cit.*

of a few species of no stratigraphic value. Several formations include numerous coal seams. Well logs and surface sections may be correlated remarkably well over large distances and there is practically no reason to assume unconformities or even disconformities within the Tertiary of this facies province. It seems that the sequence covers the whole time from the Cretaceous to the Miocene without a gap, with the possible exception of the base of the Mirador sandstone. The absence of Paleocene and of lower and upper Oligocene fossils is probably due to the general scarcity of fossils rather than to the gaps assumed by Sutton.

The formations recognized in this area are the following from top to bottom.

Barco Concession	*Sutton's Paper* (Tachira foothills)	
Necesidad	Necesidad	Pliocene?
Guayabo	Guayabo, Betijoque	Miocene
León	Isnotú	
	Palmar	
Carbonera	Bebedero	Oligocene
	Lobaterita	Eocene
	Omuquena	
Mirador	Misoa	
Los Cuervos		
Barco	Angostura	

It is necessary to discuss the subdivision and correlations proposed by Sutton. The subdivision used in the Barco concession will serve as a base for this discussion, as it is well defined and checks closely with the writer's observations in the Colón district and in the state of Táchira. Firstly, it is the writer's opinion that Sutton's Palmar and Isnotú formations are one and the same. He studied both type sections which by the way, are located in the Bolivar province, in 1942 and could see no difference between them either lithologically or in stratigraphical position. Comparison of the lithological description of the two formations given by Sutton clearly indicates a striking similarity. Both formations are found at the respective type localities above upper Eocene shales, with which they are in unconformable contact and below the sands and conglomerates of the Betijoque formation. It is, therefore, proposed to eliminate the name Isnotú formation, since the outcrops near Mesa del Palmar (Palmar on Sutton's map), in Río Buenavista, are better suited for a type section than those at Isnotú.

Although Sutton assigns the Palmar formation to the lower and middle Miocene and the Isnotú to the upper Miocene, he cites no paleontological evidence from the Isnotú formation which would contradict the elimination proposed above in the foregoing paragraph.

Secondly, the correlation between the Palmar formation and the León formation must be studied critically. The type locality of the Palmar formation lies in the state of Trujillo, in the Bolivar province. If the Palmar formation extended from there as far as the Colombian border, it would have to be exposed along the

northern foothills of the Andes in a continuous belt; only then could it be followed with certainty and traced into the León formation. This is, however, not the case. There are large gaps in the exposure of the Miocene amounting to 20 kilometers across the Avispa massif and a similar distance near Río Tucani and Río Pino. Mistakes in correlation are easily made under such conditions, especially when the outcrops of the individual sections are discontinuous and poor.

Thus, the outcrops of Caño el Tigre (central Mérida, approximately 36 kilometers north-northwest of the city of Mérida) assigned by Sutton to the Palmar formation (p. 1701) are very different from the mottled clays and sandstones exposed in Río Buenavista. They consist, according to the writer's observations, almost entirely of light gray, marine fossiliferous shales. It seems that Sutton correlates a predominantly brackish-terrigenous formation with a predominantly marine formation, unfortunately without giving any evidence. The shales exposed in Caño el Tigre, on the other hand, can actually, on the strength of their fossil content, be correlated with those cropping out at the Uracá bridge[11] which in turn represent the upper part of the León formation (Kehrer's Upper Shales).[12] We shall revert to this question later when discussing the correlation between the facies provinces. At present it seems preferable to restrict the use of the term Palmar formation to the state of Trujillo, that is, the vicinity of the type locality, as long as definite paleontological proof for a correlation from Rio Buenavista to Caño el Tigre and the Uracá outcrops has not been adduced.

A third point regards the Lobaterita formation. The type section described by Sutton (p. 1677) from Río Lobaterita represents not the upper part of Kehrer's "Sandy Shale Horizon," but his "Upper Shales" which are the equivalent of the León formation. The Tertiary sequence of the Colón province contains only one shale body comparable with Sutton's Lobaterita formation, namely, the León shales. Sutton's description of the type section could be applied without change to any section of the León formation along the Tarra ridge or in the wells of the Los Manueles field or of the Barco concession. The term Lobaterita is, therefore, unnecessary as it is equivalent with the term León. The difference in age assumed by Sutton is based on very scanty evidence as he points out himself (p. 1678). The microfaunas of the two formations are nearly the same and of no stratigraphical value, while marine shales with macrofaunas occur in the upper part of the León formation at a few places only, namely, in the area of Caño el Tigre, near Uracá and in the Rubio basin (southwestern Táchira). They seem to represent a marine ingression corresponding with the La Rosa-Lagunillas formations of the Bolivar field.

If we are correct in assuming that Sutton's Lobaterita formation is identical with the León formation, then the terms Omuquena and Bebedero formation can also be eliminated. Obviously, the "Omuquena" is equivalent to the Car-

[11] L. Kehrer, "Some Observations on the Stratigraphy in the States of Táchira and Mérida, S.W. Venezuela," *Bol. Geol. y Min.*, Vol. 2, Nos. 2–4 (Caracas, 1938).

[12] F. B. Notestein *et al.*, *op. cit.*

bonera formation (Kehrer's "Sandy Shales"), while "Bebedero formation" is a new name for the basal part of the Guayabo formation. In fact, the lithological descriptions given by Sutton fit these formations very well, and paleontological evidence is not contrary to the foregoing correlation.

As a result of the preceding considerations we obtain the following simplified subdivision for the Colón province.

Formation	
Necesidad	
Guayabo	
León ("Upper Shales")	
Carbonera ("Sandy Shales")	
Mirador	
Los Cuervos, Barco	Angostura ("Third Coal horizon")[13]

MARA PROVINCE

The Mara province covers the northwestern corner of the basin, that is, the districts of Maracaibo, Mara, and Paez of the state of Zulia. The best outcrop sections are found in the Dibujo synclinorium (called Manuelote syncline by Sutton) at the foot of the northern Sierra de Perija, in the district of Mara. In this province the Tertiary is mainly present in a brackish-terrestrial facies which is poor in fossils. Numerous coal seams occur in some of the formations. It is, however, difficult to correlate in detail the various Tertiary formations of the Dibujo synclinorium with those of the area east of it. In the Mara province the Plio-Miocene is transgressive on the older Tertiary and in the area adjoining the east flank of the Dibujo synclinorium, north of the Río Palmar, unconformably overlies part of the outcropping igneous and metamorphic rocks of the basement.

Tertiary correlation between the Mara and the Bolivar provinces is difficult. When comparing these two regions one of the main difficulties lies in the fact that the marine upper Eocene of the Bolivar province, which is rich in fossils, so far can not clearly be recognized in the Mara province. This could perhaps be explained by assuming a difference in facies of the upper Eocene or also it might be possible that these layers were either not deposited in the Mara province or were eroded off prior to deposition of the Plio-Miocene.

The formations described from this area are the following, from top to bottom.

Hedberg and Sass[14]		*Sutton*	
Milagro		Milagro, Cerro Vigia	Pleistocene
La Villa, Los Ranchos		La Villa, Los Ranchos	Miocene
Orumo		Las Flores	
Mostrencos	Taparito member, Barqueta member		
Paso Diablo		Potreritos[15], Misoa, Marcelina	Eocene
Guasare		Guasare	Paleocene

CORRELATION BETWEEN FACIES PROVINCES

It was necessary to discuss the Tertiary of the three facies provinces somewhat at length before a correlation could be attempted. Since nothing is known of the interior of the basin, a correlation must make use of observations made on its rim, that is, in the narrow belt of Tertiary exposed along the foot of the Perijá Mountains and the Mérida Andes, and the evidence from the exposures and wells in the neighborhood of Maracaibo and in the Bolivar district.

Direct correlation from the Mara to the Colón province along the foot of the Perijá Mountains is hampered by the fact that the Eocene is greatly reduced in the central Perijá district. It is represented by the La Sierra formation only, which is about 100 meters thick and lies unconformably on the Cretaceous. This indicates conditions of sedimentation entirely different from those of the Colón and Mara provinces. The presence of a wide, elevated, at times emerged area separating both provinces must be assumed, explaining the differences between the Eocene on the north and south.

Similar conditions occur along the northern foothills of the Andes. A rapid thinning of the Eocene can be observed from the area of Mene Grande (more than 4,000 meters) to the region of Betijoque (approx. 1,300 meters) and thence in southwesterly direction. Just east of the Avispa massif the thickness of the Eocene is reduced to approximately 200 meters, consisting of 100 meters of Misoa formation overlain by 100 meters of dark gray shale.

West of the Avispa massif, in the Onia area, a very thick Tertiary sequence of brackish-terrigenous character similar to the Colón facies can be observed. The presence of a threshold separating the two facies provinces suggests itself. Unfortunately, there are no Tertiary outcrops in the Avispa area over a stretch of about 20 kilometers as can be seen on Sutton's map or on the one published by L. Kehrer and E. Kündig.[16] While the writer does not pretend that a correlation of the Misoa formation across this gap into the Mirador sandstone is excluded, he would at least state that it is very difficult to prove in view of distance and facies change involved, and should be demonstrated carefully and in detail. Yet, Sutton simply states (p. 1669) that the Mirador sandstone "has recently been

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[13] The term Third Coal horizon as used in the fields of the Colón district coincides not completely but near enough with the Barco and Los Cuervos formations of the Barco concession. See Notestein *et al.*, *op. cit.*

[14] H. D. Hedberg and L. C. Sass, "Synopsis of the Geologic Formations of the Western Part of the Maracaibo Basin, Venezuela," *Bol. Geol. y Min.*, Vol. 1, Nos. 2–4 (Caracas, 1937).

[15] Although Sutton's columnar section of the northern Sierra de Perijá does not show the presence of the Misoa formation in this area, he mentions (p. 1667) that it reappears along the western limb of the Manuelote syncline. In view of our correlation Misoa-Potrerites, the Misoa formation can probably be left out in the subdivision of the Mara province.

[16] L. Kehrer, "Some Observations on the Stratigraphy in the States of Táchira and Mérida, S.W. Venezuela," *Bol. Geol. y Min.*, Vol. 2, Nos. 2–4 (Caracas, 1938).
E. Kündig, "The Pre-Cretaceous Rocks of the Central Venezuelan Andes with Some Remarks about the Tectonics," *ibid.*

traced around the south edge of the basin and into the type Misoa by Wolcott, with the exception of several breaks due to faulting between Río Buenavista and Río Mucujepe in Mérida."[16] Some supporting evidence for this statement would be very desirable.

Correlation from the Bolivar to the Colón province is thus, in the writer's opinion, not yet well established. Correlation between the Bolivar and Mara provinces also suffers from scarcity of fossil evidence and large gaps between the sections. Therefore, it seems preferable, for the time being, to use the subdivision introduced by Hedberg and Sass in the Dibujo synclinorium.[17]

Everything said so far leads to the conclusion that the majority of our correlations in the Tertiary of the Maracaibo basin are little more than assumptions, since supporting evidence in the form of fossils or of direct tracing from well to well and along the surface is mostly lacking. Correlations should, therefore, be based on general geological considerations. We must look for geological events which affected the whole area and try to determine their approximate age with the help of the few fossiliferous formations which have so far been determined. For this purpose, we shall take the Colón facies as a basis for comparison, because its sedimentation was most probably uninterrupted—or nearly so—and any change in it must have a reason lying outside the Colón province proper.

Five significant stratigraphical changes can be observed in the Colón facies.

1. A transition from marine to brackish facies at the base of the Tertiary connected with a strong influx of terrigenous material.

2. A strong influx of quartz sand culminating in the deposition of small quartzite pebbles (Mirador formation).

3. A rapid change from a sandy-shaly sedimentation to deposition of pure shales (base of the León formation).

4. A marine ingression in some parts of the Colón province (uppermost part of the León formation).

5. A rapid change to terrigenous sedimentation (base of the Guayabo formation).

We shall now try to trace these changes into the other facies provinces and to see whether corresponding features can be found.

BASE OF TERTIARY

The strong change in sedimentation at the base of the Tertiary of the Colón province is dated approximately by the determination of the Mito Juan formation as Maestrichtian. Unfortunately, the lowermost Tertiary is barren of fossils, but as the sequence seems to be continuous, the presence of the Paleocene can be assumed.

A similar transition and facies change probably occurs in the Mara province from the Colón-Mito Juan shales to the Guasare formation. The latter is assigned to the upper Paleocene on some fossil evidence. So far, however, no convincing evidence for a gap at the base of the Guasare has been adduced while well data

[17] H. D. Hedberg and L. C. Sass, *op. cit.*

from La Paz and Mara seem to indicate a transition from Cretaceous to Paleocene.

According to Sutton, Paleocene occurs in some areas of the Bolivar province, for example, the state of Trujillo (Sutton, p. 1658) where larger Foraminifera of Paleocene age were found in limestones. He assigns these beds to the Guasare formation although no such fossils were so far found in the type area of this formation. In the state of Trujillo, however, there is some indication of a gap below the base of the Tertiary as it seems that in this region the Mito Juan formation is absent. The change from a marine to a brackish facies observed in the Colón province may, therefore, be due to a general uplifting of the area of the Maracaibo basin which in some parts resulted in erosion and in others in influx of terrigenous material.

Much work remains to be done to establish these relations clearly. Observations at the contact of Cretaceous and Tertiary are unfortunately limited, due to lack of good surface sections. In many places, the contact is hidden by rubble descending from the Tertiary sandstone ridges onto the strongly eroded Cretaceous shales. The soft nature of the shales also makes it difficult to discover unconformities, since hardly any pebbles can be found in the transgressing formations. This is the case in the La Sierra formation which is known to transgress the Colón formation.

INFLUX OF MIRADOR QUARTZ

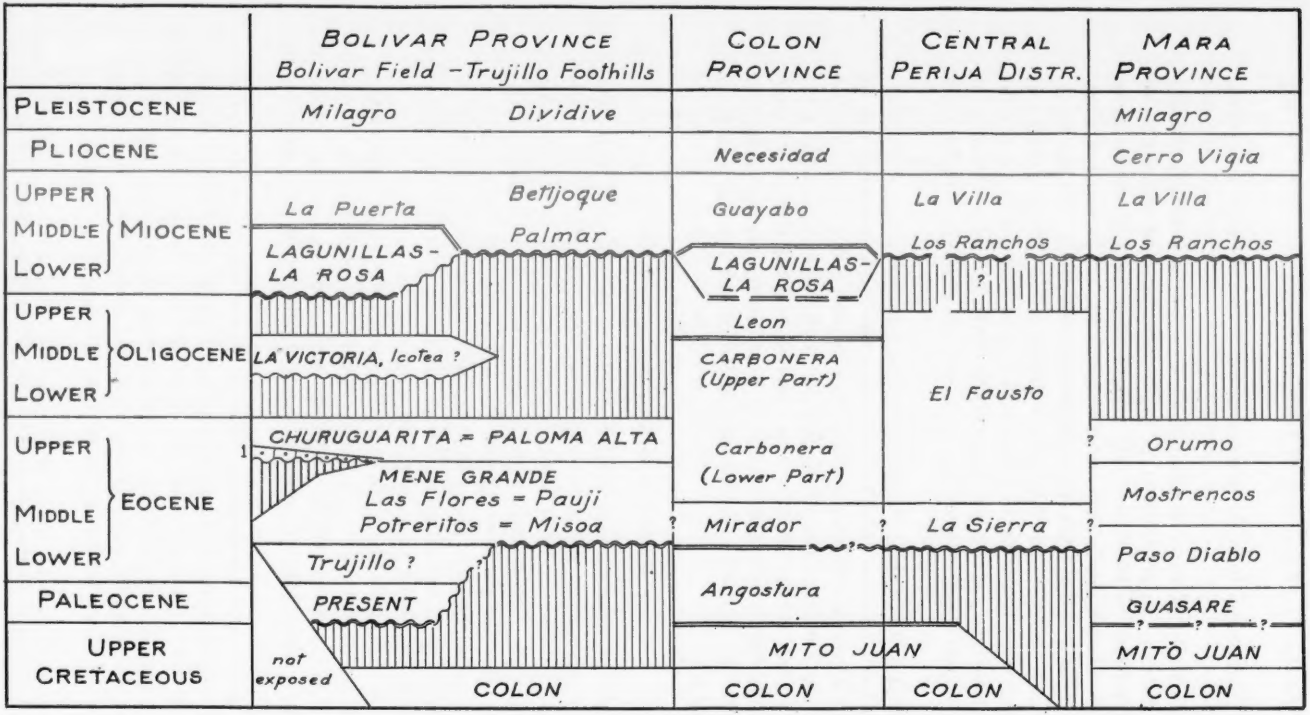
The strong influx of quartz and quartzite pebbles of the Mirador formation must be connected with uplift and erosion in some area adjacent to the Colón province. This may explain the local unconformities at the base of the Mirador mentioned by Notestein. The westerly and northerly increase in thickness of the formation indicates that the source of the material was at the west and northwest. An uplift in this area might have been connected with the unconformity known at the base of the La Sierra formation in the central Perijá district which transgresses progressively over older beds from east to west.

Another, similar indication which might lead to some correlation between the Colón and Bolivar provinces is offered by the apparent transgression of the Misoa formation on the Colón shales in the western part of the state of Trujillo. Strong lithological similarity of the Misoa exposed in this area with the Mirador provides an additional argument.

On the other hand, an unconformity is known in the upper Eocene of the Bolivar province, at the base of the Paloma Alta-Churuguarita formation. Erosion must have reached the Cretaceous and metamorphic rocks at this time, as is proved by the presence of pebbles of chert quartzite, and crystalline rocks in the Sta. Rita and Venado conglomerates.[18] There are thus two possibilities for correlation on this basis of which the writer favors the former.

[18] A. Senn, "Paleogene of Barbados and Its Bearing on History and Structure of Antillean-Caribbean Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 9 (September, 1940), p. 1589.

TABLE I



Legend:

unconformity

gap

1 Venado–Sta Rita conglomerate

Proposed correlations are marked by double lines. CAPITALS indicate that the age of the formation has been determined approximately by fossil evidence.

GENERALIZED CORRELATION CHART OF THE TERTIARY MARACAIBO BASIN

BASE OF LEÓN FORMATION

The change of sedimentation at the base of the León formation indicates a diminished influx of coarse terrigenous material which was possibly caused by a slight deepening of the sea in the upper/middle Oligocene. Unfortunately not much is known about the equivalents of the León formation in the other provinces where this stage is eliminated in many areas by the Miocene unconformity. It may be possible to obtain a correlation with areas farther east, in the state of Falcon where Senn[19] observed a transgression at the basis of the middle Oligocene San Luis formation.

MARINE INGRESSION IN MIOCENE

A marine ingression apparently not connected with any disconformity or unconformity is known from certain parts of the Colón province, for example, the region of Uracá. It is situated in the upper part of the León formation. The fossils found in these beds show that they are connected with the marine ingressions of the La Rosa and Lagunillas formations of the Bolivar field which are usually said to be lower Miocene in age. A comparison of the fossils collected near Uracá (Sutton, p. 1702), with those from the La Rosa and Lagunillas formations (Sutton, pp. 1695–96 and 1700) indicates a somewhat closer affinity with the La Rosa than with the Lagunillas formation.

BASE OF GUAYABO FORMATION

The sudden influx of terrigenous material at the base of the Guayabo formation points to renewed positive movements around the Colón province. This influx is approximately dated as lower middle Miocene by the marine ingression immediately underneath. In the Mara province and in the southern Bolivar province a strong unconformity exists at the base of very similar Miocene formations which transgress onto the Eocene, the Cretaceous and even onto the basement. The deposition of these formations was preceded by a period of folding, uplift, and erosion. It is probable, therefore, that the material of the Guayabo formation originates partly in the uplifted and eroded areas of the Bolivar and Mara provinces. The base of the Guayabo formation can on this basis be approximately correlated with the base of the Los Ranchos formation in Perijá-Mara and of the Palmar formation in Trujillo.

CONCLUSION

On the basis of present information the writer ventures to correlate the Tertiary sequences of the different facies provinces of the Maracaibo basin tentatively as indicated. The results of these considerations have been assembled in Table I. Obviously they are very uncertain and serve more to indicate the gaps in our knowledge than to fill them. In conclusion it can be said that a great deal remains to be done before the stratigraphical problems presented by the Maracaibo basin can be brought nearer to solution.

[19] A. Senn, *op. cit.*, and "Die stratigraphische Verbreitung der tertiären Orbitoiden *etc.*," *Eclogae Geol. Helvetiae*, Vol. 28, No. 1 (1935).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 2 (FEBRUARY, 1948), PP. 228-251, 9 FIGS., 2 TABLES

SLICK-WILCOX FIELD, DEWITT AND GOLIAD COUNTIES, TEXAS[1]

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San Antonio, Texas

ABSTRACT

This paper presents a summary of the history, geology, and development of the Slick-Wilcox field, DeWitt and Goliad counties, Texas, from its discovery until April, 1947.

The Slick-Wilcox field is located on the DeWitt-Goliad County line southeast of the town of Nordheim. The surface is underlain by southeasterly dipping Tertiary beds.

Oil was discovered in the "Pettus" sand in the Cockfield member of the Yegua formation in December, 1930. Discovery was the result of surface structural mapping. Shallow "Pettus" production was largely abandoned after 1937, and deeper oil was produced from the third sand of the upper Carrizo-Wilcox section in May, 1943. Location for the well which discovered the deeper producing sand was made from subsurface information gained from geophysical prospecting.

The accumulation of oil occurs in a faulted dome. The oil is trapped against a normal fault upthrown on the north.

The oil is being produced by a combination of the forces resulting from a natural water drive and an expanding gas cap. There are 48 producing oil wells in the field. By the end of March, 1947, the field has produced 4,339,599 barrels of oil from the producing zone in the Carrizo-Wilcox. The original recoverable reserve is estimated at 20,000,000 barrels of oil.

LOCATION AND TOPOGRAPHY

The Slick-Wilcox field is on the Dewitt-Goliad County line, 6 miles southeast of the town of Nordheim. It may be reached from Nordheim, Yorktown, Weesatche, or Goliad over dirt roads leading to the field.

The topography is one of gently rolling hills with approximately 100 feet of relief. The surface formations are Goliad in age with some caliche outcrops. These sedimentary rocks weather into dark loams and alternating exposures of lighter sandy soils. More than half of the field area has never been cultivated, and this part is rather densely covered with low scrub and live-oak trees, some mesquite, and associated underbrush.

The field is in the area of the southeasterly dipping Tertiary beds of the Texas Gulf Coast, and it is on the subsurface extension of the large structural feature called the San Marcos arch, midway between the Rio Grande and East Texas embayments. The field is on the northern side of a fault zone where this zone, trending generally northeastward across central Live Oak, northern Bee, and northern Goliad counties, locally changes directions abruptly toward the east.

[1] Presented as a thesis to the faculty of the Graduate School of The University of Texas in partial fulfillment of the requirements for the degree of Master of Arts. Read before the South Texas Section at San Antonio, June 23, 1947, and before the South Texas regional meeting, at San Antonio, November 6, 1947. Manuscript received, November 12, 1947.

[2] Standard Oil Company of Texas. The writer is especially indebted to Ira H. Stein, Alice, Texas, who suggested the subject of the paper, furnished much of the material, and contributed his advice and suggestions as difficulties with the problem arose. Personnel of the Continental Oil Company and the Sunray Oil Corporation generously contributed base maps, production statistics, and other data on the field. Rual B. Swiger, San Antonio, Texas, furnished most of the material on the old, and now abandoned shallow Slick field. Professors H. H. Powers, F. L. Whitney, and especially Hal P. Bybee, all faculty members of The University of Texas, contributed valuable advice and suggestions on the paper.

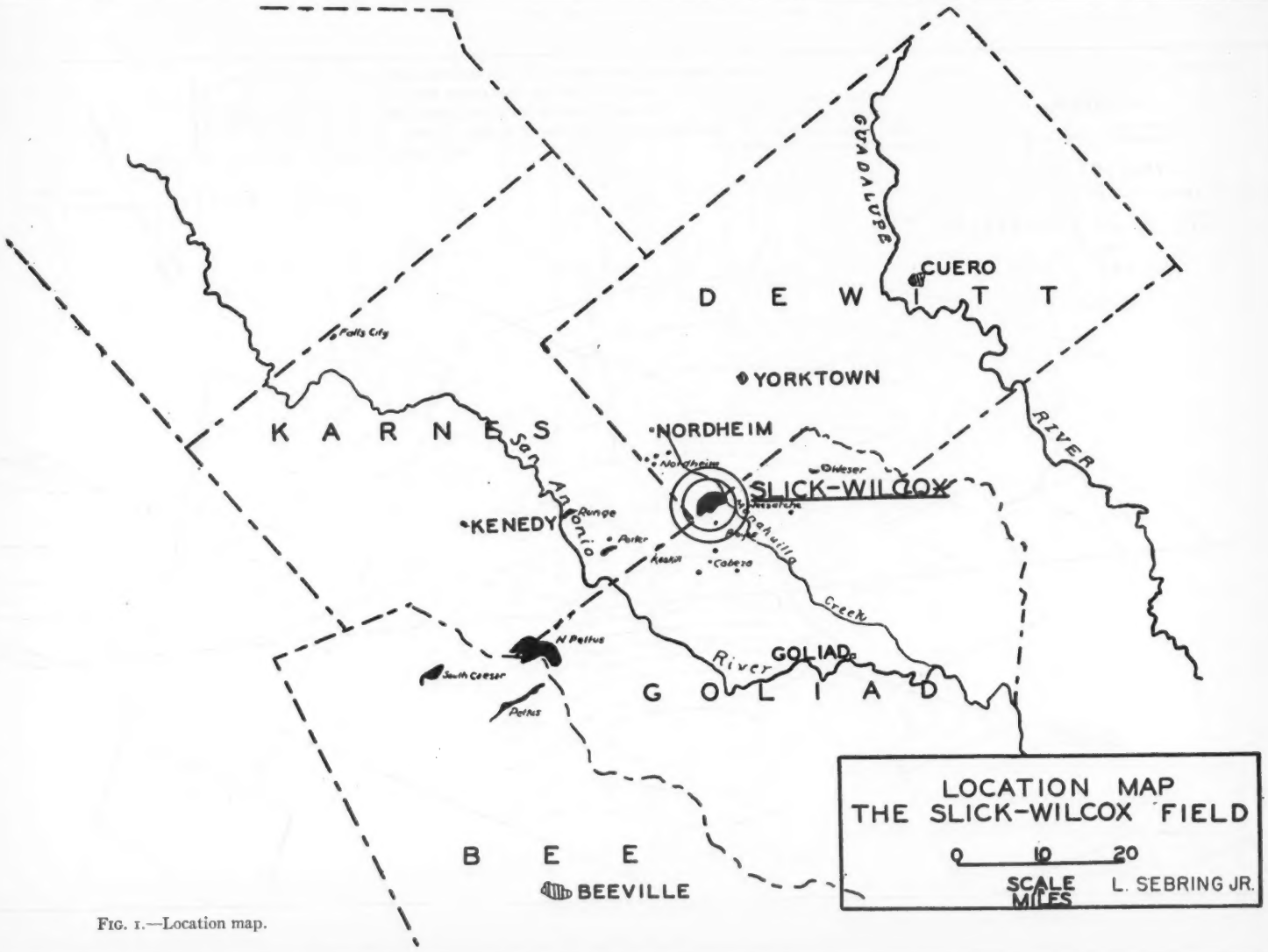


FIG. 1.—Location map.

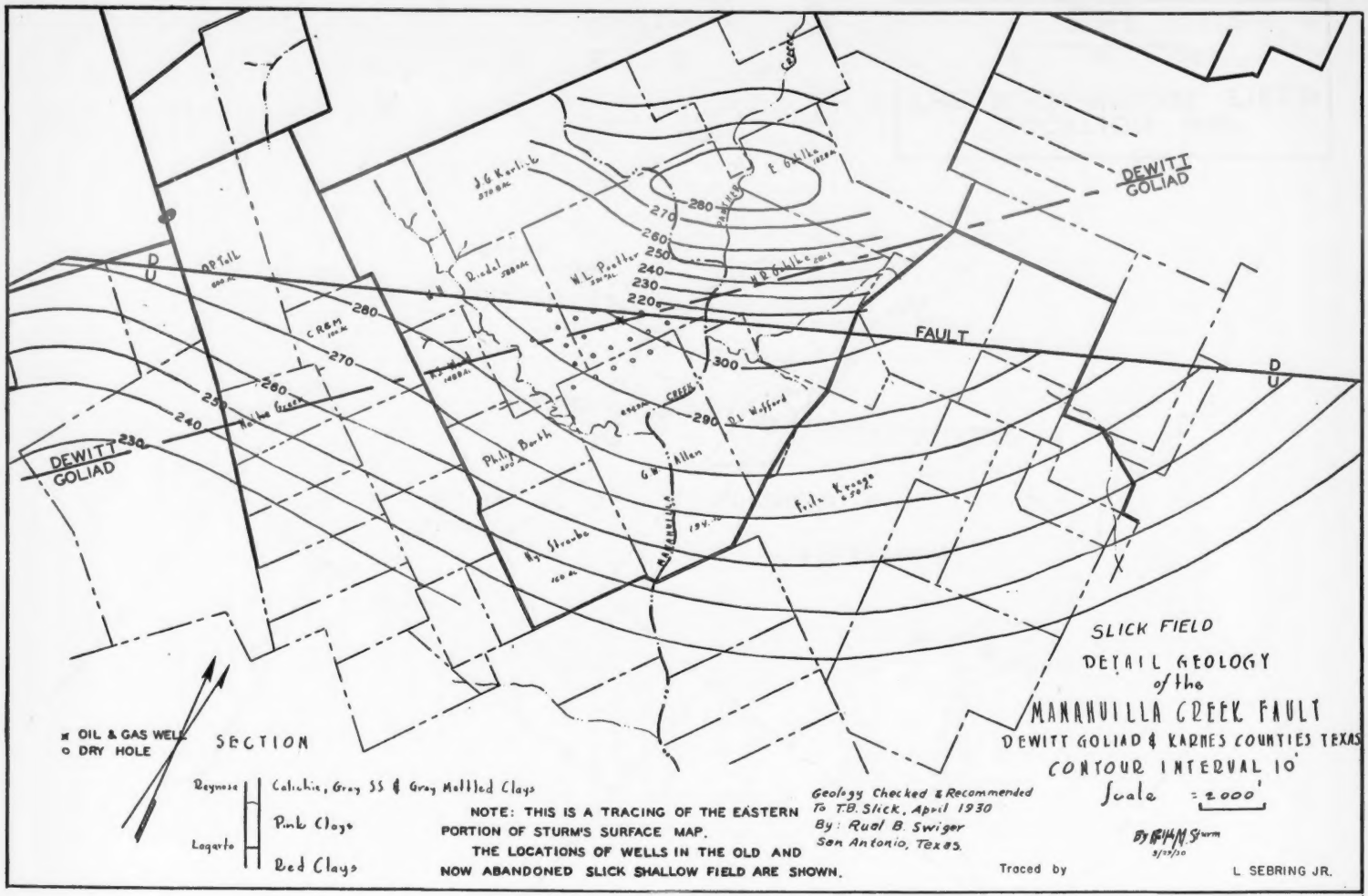


FIG. 2.—Surface structure map by Sturm and Swiger.

FIG. 2.—Surface structure map by Sturm and Swiger.

HISTORY

The first oil discovered in the Slick field was found in the shallow "Pettus" sand of Cockfield (upper Yegua) age. The discovery well was drilled by T. B. Slick on the W. L. Poetter farm in the Obid Marshal Survey to the total depth of 4213 feet. It was completed on December 22, 1930, producing 545 barrels of oil per day, and approximately 10 million cubic feet of gas per day through $\frac{1}{4}$-inch choke.

The location for the discovery well was made by Rual Swiger in April, 1930, on the basis of surface geological mapping done by Ralph M. Sturm. Sturm, his task rendered difficult by brushy terrane and a soil cover, nevertheless did an extremely competent job of recognizing and mapping the surface anomalies resulting from doming and faulting. As there are no exposures of the faulting here, Sturm, presumably by mapping soil changes and noting local steepening of dip of the surface beds, correctly inferred the presence of faulting.

However, he mapped this fault as upthrown toward the south. Swiger,[3] in checking Sturm's work, reversed the upthrown and downthrown sides of the fault, mapping the upthrown side on the north. This interpretation is presumably correct.

After this auspicious beginning, about 15 additional shallow wells were drilled in the area with varying results. Generally, however, the shallow production was not profitable. Seven of these later wells were drilled to the Pettus before September, 1933. Of these seven wells, two were completed as gas wells with an initial production of 25 million cubic feet per day with some oil; two were dry but with a showing of oil; the remaining three wells were dry. Since no pipe-line facilities to the field were available at this time, there was little incentive to develop the gas production. All of the oil was transported from the field to the refineries by truck.[4]

By January 1, 1937, the field had produced 69,270 barrels from the shallow "Pettus" zone, and since then shallow production has been negligible.[5]

In March, 1943, the Continental Oil Company commenced operations on its Wood No. 1. The location for this well was made on the basis of seismograph work done by the Transwestern Oil Company (since purchased by Sunray) and interpreted by J. A. Culbertson of the Continental Oil Company.[6] This was the discovery well of the Slick-Wilcox field. The well was completed, May 14, 1943, from perforations at 7,600–7,620 feet, for 232 barrels per day on 5/32-inch choke, tubing pressure 1,075 casing psi,[6a] pressure 1,460 psi, gravity 36.4° A. P. I., gas-oil ratio 439–1.

[3] Rual B. Swiger, letter dated March 12, 1947.

[4] R. B. Swiger, *Report on the Slick Field, Goliad and DeWitt Counties, Texas*, for Trust Estate of T. B. Slick (September 25, 1933).

[5] I. H. Stein, *Slick Field, DeWitt and Goliad Counties*, unpublished paper given before the Corpus Christi Geological Society, Corpus Christi, Texas (1944).

[6] I. H. Stein, *op. cit.*

[6a] Pounds per square inch.

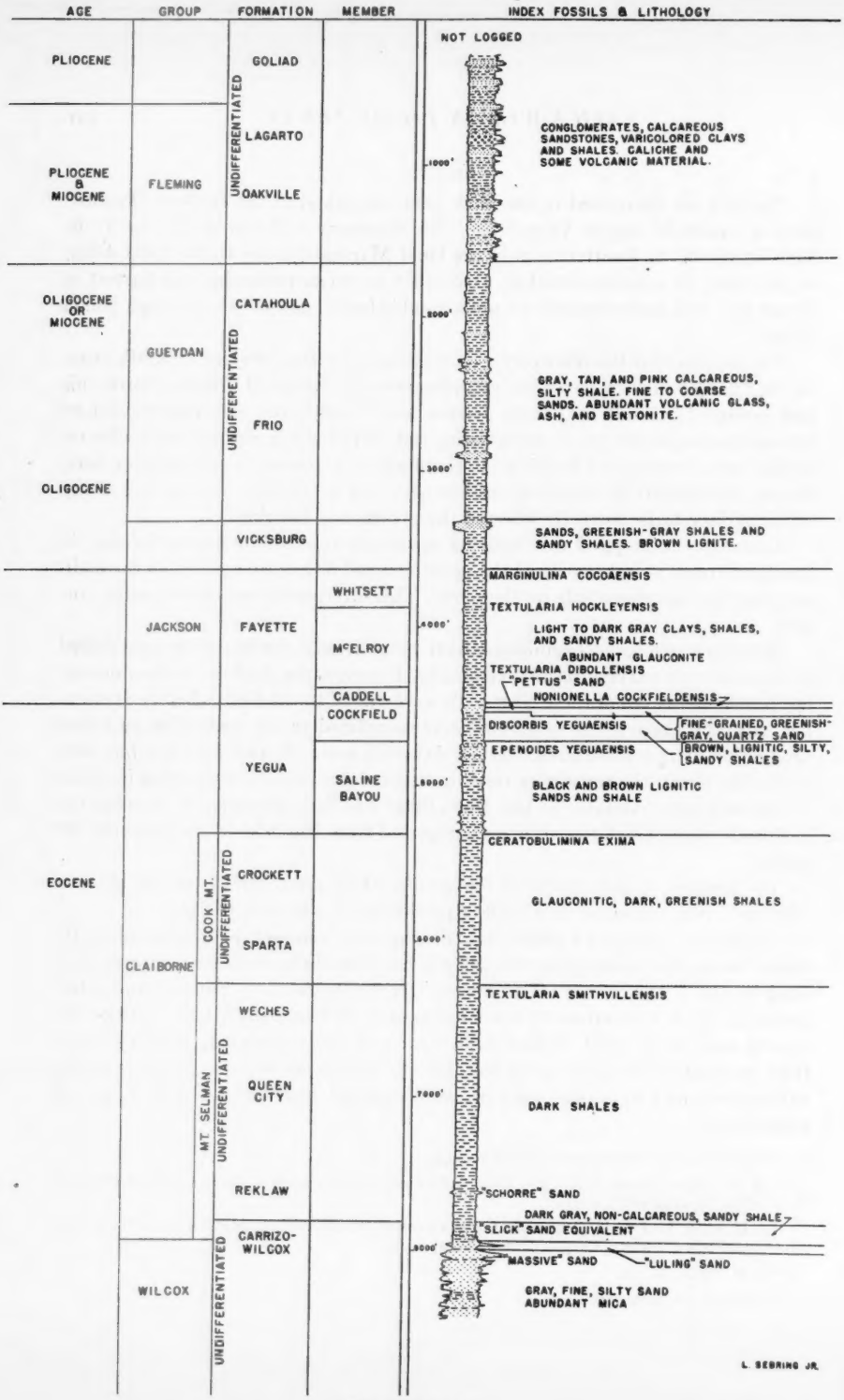


FIG. 3.—Type log.

STRATIGRAPHY

GENERAL

Alternating marine and non-marine deposits make up the Tertiary beds of the Texas Gulf Coast. Marine deposits generally contain characteristic microfauna which serve as recognizable markers in the subsurface samples. As the non-marine beds are mainly non-fossiliferous, they are differentiated with greater difficulty than the marine beds.

Tertiary formations, of both marine and non-marine origin, consist of alternating sands, shales, and clays. These beds, no matter what their age, are very similar. Volcanic ash, glass, and bentonite are found in many of the formations. In the deposits under consideration, no limestone beds are known, although calcium carbonate occurs as a secondary deposit in most of the formations. Because of this lithologic similarity, separation of some of the beds into units is very difficult.

The Tertiary formations crop out in narrow bands which parallel the coast of the Gulf of Mexico. All beds dip toward the coast and the outcrops of the older formations are exposed from the Gulf of Mexico inland. The location of the Slick-Wilcox field on the San Marcos arch probably has some effect on the stratigraphy of the local area.

A factor making correlation difficult between the beds at the outcrop and their subsurface equivalents is the common and rather rapid changes in facies downdip from the outcrop. This phenomenon is natural and to be expected as the sediments at the outcrop are generally continental or near-shore in facies of deposition. Gulfward, or downdip, marine or deepening water conditions of deposition are encountered. Consequently, the finer-grained shales, clays, and muds begin to predominate over the coarser sediments. Also, these marine beds commonly contain marine fossils that are not found at the outcrop. Most of the beds thicken greatly downdip. Some formations encountered in the subsurface have no known surface equivalents. Even if the downdip formation has a surface equivalent, the correlation between the sediments of the same age, but with different lithological characteristics and an unlike faunal content, is generally difficult.

Figure 3 shows the position of the various formations as they are discussed in the following paragraphs.

EOCENE SERIES

WILCOX GROUP

Carrizo-Wilcox section.—As pointed out by Culbertson,[7] Reedy,[8] and others, it has proved expedient to combine the basal formation of the Claiborne (Carrizo) and the Wilcox into one formation in the downdip facies of these beds. The beds

[7] J. A. Culbertson, "Downdip Wilcox (Eocene) of Coastal Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 11 (November, 1940), pp. 1891–1922.

[8] M. F. Reedy, "Sections in the Eocene of the Gulf Coastal Plain of Texas and Louisiana," Master's thesis, The University of Texas (1939).

are lithologically similar and there seem to be no differentiating characteristics. In beds of Wilcox age at some distance from the outcrop, it has not been feasible, thus far, to subdivide the Wilcox into its surface equivalents (Seguin, Rockdale, and Sabinetown). Because of the abundant coarse, clastic materials in the Carrizo-Wilcox section, it is easily recognized on electrical logs below the long shale sections of the Mt. Selman.

In the Slick area the Carrizo-Wilcox consists of carbonaceous shales and fine sands containing abundant mica. There are no known index microfossils in this part of the Carrizo-Wilcox. The sample log for the Continental Oil Company's Wood No. 1, described this section as follows.

Feet	
7399–7536	Dark gray, brittle, non-calcareous "ringtail" shale; residue; dark gray shale fragments, glauconite
7536–8002	Gray, fine, glistening, hard, sugary, silty sand; residue; fine, glistening sand—porous, micaceous

The section, where penetrated in the Slick-Wilcox field, contains a basal shale section of unknown thickness. Above the shale are approximately 700 feet of thick sands with only thin shale breaks interrupting the vertical continuity of the sand. This sand body, the main oil- and gas-producing zone of the field, is locally called the "Massive" sand.

Above the "Massive," interrupted by 30–50 feet of shale, is another sand section named the lower "Luling" sand. This sand body has a normal thickness of approximately 20 feet. The section contains gas, and a few wells in the field have been completed as gas wells in this sand; however, no oil level has been discovered in the sand.

After another overlying shale break of 100 feet, there occurs a thin sandy bed approximately 20 feet thick. This bed which is generally so shaly in most of the field wells that it is marked only by a shoulder on the resistivity side of the electrical log, has been correlated by I. H. Stein as the "Slick" sand equivalent.[9] This section produces gas from the Phillips Petroleum Company's Kraege No. 1. The "Slick" sand is considered the top of the Carrizo-Wilcox section.

It should be pointed out that the "Slick" and the "Luling" sands were named from producing sands in the South Caesar field, Bee County, Texas. The three producing sands can be differentiated by electrical logs throughout Goliad, southern DeWitt, northern Bee, and central Live Oak counties.[10]

CLAIBORNE GROUP

Mt. Selman sub-group.—Overlying the Carrizo-Wilcox beds are approximately 1,350 feet of glauconitic, dark shales of Mt. Selman age. In the Slick area the continuity of these shales is broken only by a sand occurring 190 feet above the base. This sand is locally known as the "Schorre," named from a well drilled

[9] I. H. Stein, "Slick Field, DeWitt and Goliad Counties," unpublished paper given before the Corpus Christi Geological Society, Corpus Christi, Texas (1944).

[10] I. H. Stein, personal communication, Alice, Texas (March, 1947).

in Karnes County, where a showing of oil was obtained on a drill-stem test in the sand. This sand is lower Reklaw in age.

The Mt. Selman is differentiated from the overlying Cook Mountain beds solely on the basis of its fossil content. The top of the Mt. Selman is marked by the first occurrence of *Textularia smithvillensis*. Another excellent marker of the Mt. Selman is the foraminifer *Lamarckina claibornensis*. Both of these fossils occur in the youngest formation of the Mt. Selman, the Weches. There are no electrical anomalies throughout this section, excepting that marking the basal "Schorre" sand, and the section is lithologically uniform. Therefore, in this area the Mt. Selman is not divided into its member formations of Reklaw, Queen City, and Weches. In fact, unless studies of the samples and their contained microscopic fossils is undertaken, it is impossible to differentiate the Mt. Selman and the overlying Cook Mountain beds.

Cook Mountain sub-group.—Above the Mt. Selman shales lie approximately 900 feet of dark greenish, glauconitic shales of Cook Mountain age. These beds are differentiated from the underlying beds only by a study of their fossil content. The base of the Cook Mountain is marked by the first occurrence of the fossil *Textularia smithvillensis*, which is the index fossil of the Weches formation below. The top is marked by the appearance of the guide foraminifer of the Crockett formation, *Ceratobulimina exima*. This is an excellent and easily recognized index fossil.

The discontinuity between the overlying basal sands of Yegua age and the typical Cook Mountain shales is reflected in the electrical characteristics of the sediments; therefore, the electrical anomaly corresponds exactly with the faunal and lithologic break.

Yegua formation.—The Yegua beds are the uppermost formation of the Claiborne group. They consist of slightly more than 800 feet of black and brown lignitic shales, sandy shales, and sands.

The formation is ordinarily divided into three members. The basal member of sands and sandy shales is easily recognized on the electrical logs. It has a normal thickness of approximately 600 feet and is marked by the occurrence of the index fossil *Epenoides yeguaensis*. This basal member has been called the Saline Bayou.

The middle member, or middle Yegua, is marked by the first occurrence of the index fossil, *Discorbis yeguaensis*. As pointed out by Cooper,[11] there are several species of *Discorbis* throughout this zone which are similar to the *Discorbis yeguaensis*. Ordinarily, therefore, no attempt is made to differentiate the middle Yegua from the overlying Cockfield member.

The youngest member of the Yegua formation is the Cockfield. These beds have been named from the index foraminifer of the formation, *Nonionella cockfieldensis*. Israelsky[12] has pointed out that the faunal assemblage of the Cock-

[11] R. P. Cooper, personal communication, Alice, Texas (April, 1947).

[12] M. C. Israelsky, "Tentative Foraminiferal Zonation of Subsurface Claiborne of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 5 (May, 1935), pp. 689–95.

field is more nearly related to the assemblages in beds of Jackson age, than to the assemblages of the middle Yegua and the Saline Bayou. Stenzel[13] admitted that this is true, but noted that since the stratigraphic considerations should be of of more account than a faunal similarity the Cockfield should remain in the Yegua. This would combine beds most similar lithologically into the same groups. The majority of geologists seem to share the latter view; hence, in this paper the Cockfield is considered a member of the Yegua formation.

For the most part the beds consist of brown, lignitic, silty, and sandy shales, characteristic of the Yegua formation. However, approximately 30 feet below the top, a sand bed about 25 feet thick occurs. The sand is named the "Pettus" after the Pettus field in northern Bee County, where it was a prolific producing sand. This fine-grained, gray-green, quartz sand is the sand in which the original discovery well of the shallow Slick field was completed. As the sand is an excellent electrical marker, it is very commonly used for regional mapping. This horizon was used for the shallower subsurface structural map.

JACKSON GROUP

Fayette formation.—The youngest group of Eocene age is the Jackson. In this area the group is made up of only one formation, the Fayette. Most petroleum geologists working in the area use the name Jackson as both a group and a formation name; the term Fayette is rarely used.

The Jackson or Fayette formation contains three recognizable members here, the oldest of which is the Caddell. This member, which shows an approximate thickness of 130 feet in the Slick area, is characterized by the presence of abundant glauconite and the index foraminifer, *Textularia dibollensis*. Although the top of the formation is easily recognized in sample work, its hard, gray, calcareous shales are not marked by an electrical anomaly on the log.

Above the Caddell are the beds of the McElroy member. These beds, 500 feet thick, are composed of light to dark gray, calcareous clays and shales. The top is marked by the occurrence of the index foraminifer, *Textularia hockleyensis*. These beds give no characteristic electrical anomalies in the well logs.

The top member of the Jackson is the Whitsett consisting of 250 feet of shales and sandy shales. The Whitsett is marked at the top by the foraminifer, *Marginulina cocoaensis*. *Massilina pratti* is another excellent index fossil in this zone.

OLIGOCENE SERIES

Vicksburg (?) or basal Frio formation.—Overlying the Whitsett member are slightly more than 300 feet of sands and greenish gray shales and sandy shales containing some brown lignitic material. At the top of this formation a massive sand body occurs which shows a variable thickness of 20–60 feet in the field. This sand body is easily recognizable on the electrical logs.

Although the index fossil to the Vicksburg, *Textularia warreni*, is not present

[13] H. B. Stenzel, "The Yegua Problem," *Bur. Econ. Geol. Bull. 3945* (1939), pp. 847–910.

this far updip, these beds are generally regarded as Vicksburg in age because of their stratigraphic position and lithologic character.

OLIGOCENE AND MIOCENE SERIES

Undifferentiated Frio and Catahoula formations.—Above the Vicksburg (?) are approximately 1200 feet of multicolored sands and calcareous shales, containing much volcanic glass, ash, and bentonite. As these beds are continental, they contain no index fossils. As the Frio and Catahoula are lithologically similar, they are rarely differentiated in the subsurface in this region. Although all variations in color are shown, the beds are generally some shade of gray. The sample log of the Continental Oil Company's Wood No. 1, described the cuttings as follows.

Cuttings: Gray-tan and pink, calcareous silty shales
Residue: Gray, silty sandstone fragments, fine to coarse frosted sand grains, volcanic glass

Rapid lensing or shaling-out of the sandy parts of these beds in a seemingly illogical manner, and with the increasing complexity of the faulting as the shallower beds are reached, have combined to rule out any practical attempts at correlation of the beds in this zone. No effort, therefore, was made in this paper either to map the beds or to extend the cross sections upward to include them.

The top of the Catahoula-Frio section is well marked by the electrical anomalies caused by the basal Oakville fresh-water sands. This easily recognized sand zone is often used for shallow regional mapping in the area.

MIOCENE AND PLIOCENE SERIES

Oakville, Lagarto, and Goliad formations.—The shallowest formations encountered by the drill are the Oakville (at the base), Lagarto (Week's Cuero),[14] and the Goliad. The Goliad is the outcropping formation in the Slick field. Because of their shallowness, these beds are usually not electrically logged in the deep wells. The sediments are similar lithologically, consisting of beds of conglomerates, calcareous sandstones, and varicolored shales and clays with caliche. Although volcanic material is present, it is generally found in less amounts than in the beds directly beneath. The three formations have a combined thickness in the Slick area of approximately 1,600 feet.

PRODUCING BEDS

The present producing beds of the Slick-Wilcox field are the "Massive" sand, the "Luling" sand and the "Slick" sand. All of these beds are Carrizo-Wilcox in age.

The "Massive" sand is the main producing bed of the field. This fine-grained, gray sand has an average porosity of approximately 22 per cent. The permea-

[14] A. W. Weeks, "Oakville, Cuero, and Goliad Formations of Texas Coastal Plain between Brazos River and Rio Grande," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 12 (December, 1945), pp. 1721–32.

bility varies greatly over the field, some wells averaging as low as 75 millidarcys and others as high as 1800 millidarcys (Table I). However, this variation does not seem to affect well potentials, with the size of chokes used. Some wells showing low permeability have been successfully treated with mud acids, and generally show greatly increased permeabilities after this treatment. The original gas-oil level was encountered at −7,251 feet while the original oil-water level was encountered at −7,300 feet. Thus, there was originally present a vertical oil column of 49 feet. Unfortunately there are shale beds in the "Massive" sand at these depths which serve to decrease the oil-productive section. The shale beds range from 20 to 40 feet in thickness. These beds seem to be discontinuous over the field as the oil-water and oil-gas levels are constant in sand beds apparently separated by the shale layers.

The "Luling" sand, above the "Massive" sand, contains only gas in all wells in the field. Although the sand is somewhat erratic in occurrence, it seems probable that it is capable of producing commercial amounts of natural gas in most of the field wells. As this horizon is rarely cored, no core analysis data are available.

The "Slick" sand is generally poorly developed and produces only in one well, the Phillips Petroleum Company's Kraege No. 1, where it produces gas. There are no available core-analysis data on this sand.

There are no core-analysis data for the shallow "Pettus" sand from wells located in this field.

TABLE I

CORE-ANALYSIS SUMMARIES OF A FEW REPRESENTATIVE WELLS*

Sunray Oil Corporation	*O. P. Talk 1*	*W. H. Riedel 1-B*	*W. L. C. Poetter 4*	*J. F. Wood 1*
Depth, feet	7,627–7,642	7,596–7,624	7,596–7,608	7,636–7,662
Core recovery, percentage	80	89	67	69
Feet of permeable productive formation recovered	12	14	8	10
Average permeability, millidarcys	399	219	203	392
Capacity—average permeability×feet production formation	4,788	3,066	1,624	3,930
Average porosity, percentage	21.8	20.6	21.8	24.1
Average residual oil saturation, percentage pore space	13.7	16.1	18.0	11.6
Gravity of oil, degrees A.P.I.	35	36	35	35
Average total water saturation, percentage pore space	49	44.2	41.4	55.1
Estimated solution gas/oil ratio, cubic feet/barrel	770	770	770	770
Average calculation connate water saturation, percentage pore space	41	38	33	44
Estimated formation volume factor	1.44	1.44	1.44	1.44
Calculated total recoverable oil (production by natural or gas expansion plus production by complete water drive) in barrels/acre foot	462	430	482	511

* Analyses by Core Laboratories, Inc., Dallas, Texas.

STRUCTURE

The structure on the top of the "Massive" resembles a dome which has been cut in half by two major faults with strikes almost exactly east and west. Accumulation of the oil is on the northern and upthrown side of the northernmost of the two faults. There is a closure of approximately 110 feet against this fault on the top of the "Massive" sand.

It is difficult to make a reasonable compilation of the throws of the individual faults that will be consistent over the field. This is because the values obtained for the throw vary both vertically through the section and horizontally along the strike of the fault. However, if it is considered that the major faulting took place within a zone delimited by the faults that reach the Carrizo-Wilcox as marked on the cross sections, more reasonable results can be obtained.

By using this premise as a basis for computations and calculating the minimum throw by the thicknesses of the beds cut out by normal faulting (there are no reverse faults in the area), the following values for the combined throw of the faults which affect the Carrizo-Wilcox are obtained.

From east to west	*Feet*
Section *CC'* (Fig. 8)	160
Section *BB'* (Fig. 7)	260
Section *DD'* (Fig. 9)	220

If we consider these faults as separate features, it might be well to point out that the northernmost fault which reaches the Carrizo-Wilcox has a throw of 100 feet at its eastern end (cross section *CC'*, Fig. 8), 160 feet in the center of the field (cross section *BB'*, Fig. 7), and only 30 feet at the western end of the field (cross section *DD'*, Fig. 9). This last value of only 30 feet for the throw of the northernmost fault, when an extension of the same fault has a much greater dis-

TABLE II

ANALYSIS OF WATER PRODUCED FROM "MASSIVE" SAND

		Parts Per Thousand
Calcium and magnesium	(Ca and Mg)	1,940
Sodium and potassium	(Na and K)	16,828
Iron	(Fe)	3
Hydroxide	(OH)	0
Carbonate	(CO_3)	0
Bicarbonate	(HCO_3)	473
Sulphite	(SO_3)	0
Sulphate	(SO_4)	431
Chloride	(Cl)	28,640
Soluble	(SiO_2)	160
Total solids		48,475
Hydrogen ion Concentration	(pH)	6.8
"P" alkalinity		0 as $CaCO_3$
Total alkalinity		388 as $CaCO_3$
Total hardness		4,850 as $CaCO_3$
Sodium chloride		45,468 as NaCl

Resistivity 34.3 Ohm = Cm. @ 74°F.

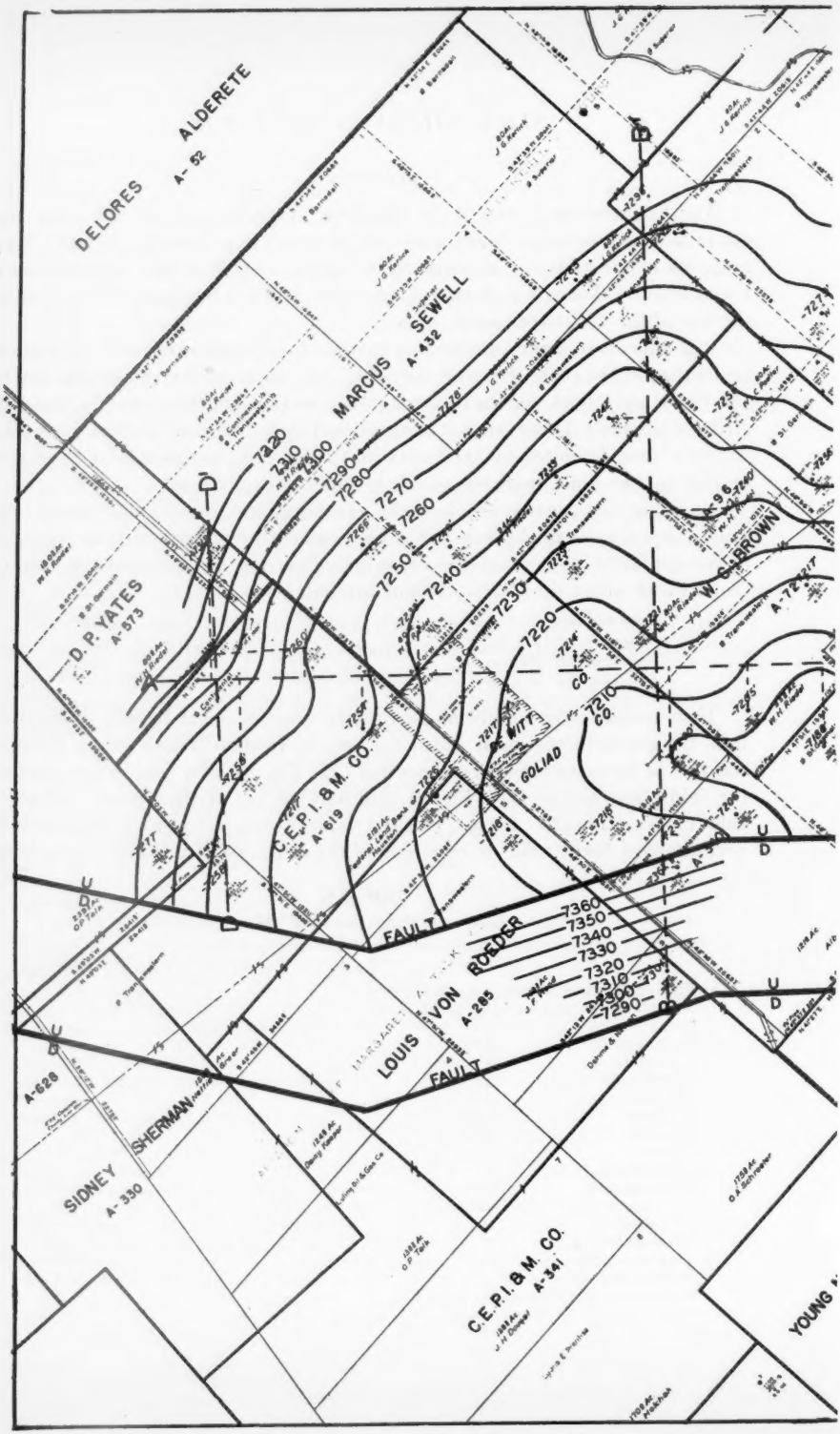
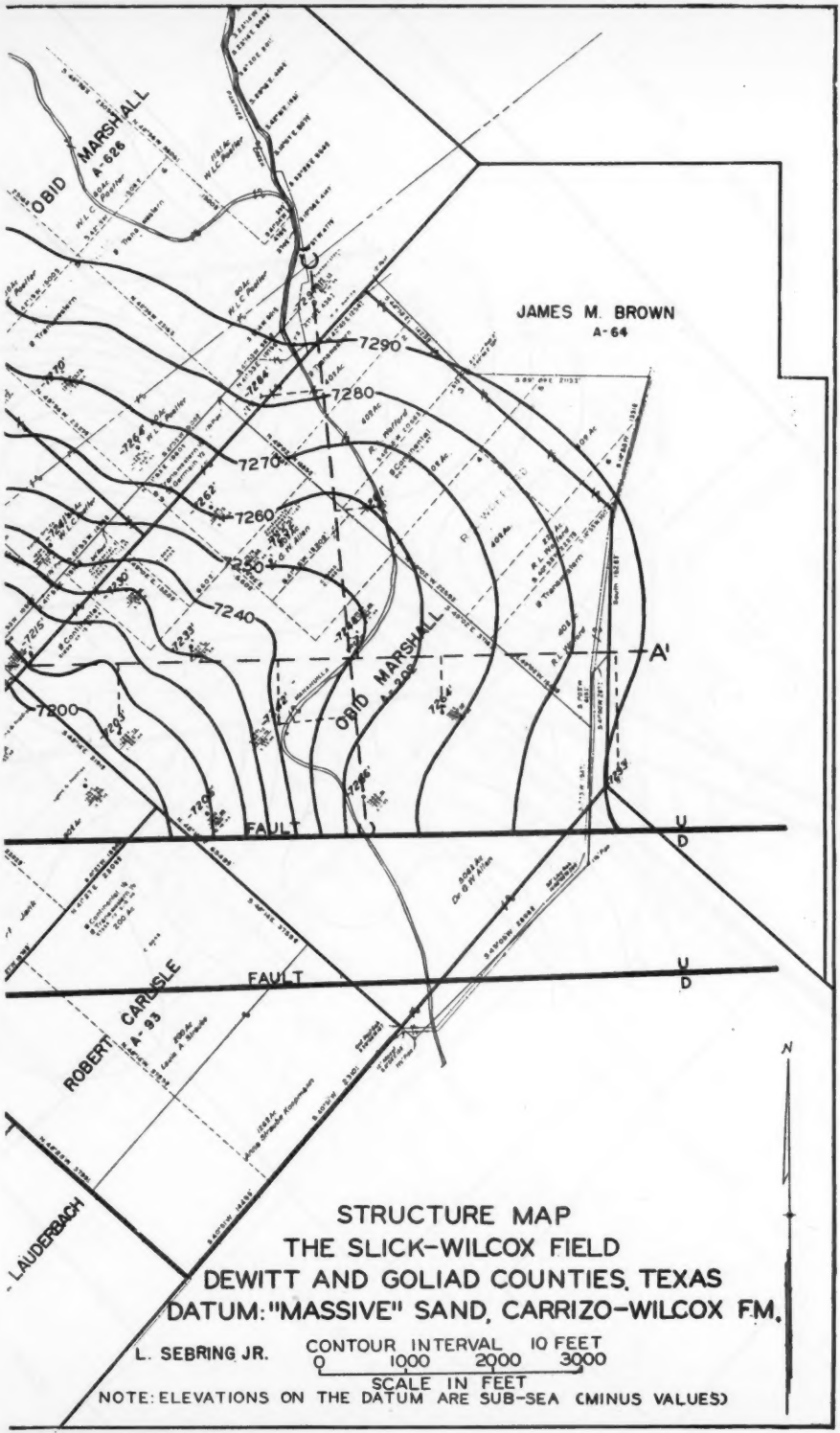


FIG. 4.—Structure map on "Massive"



sand, Carrizo-Wilcox group.

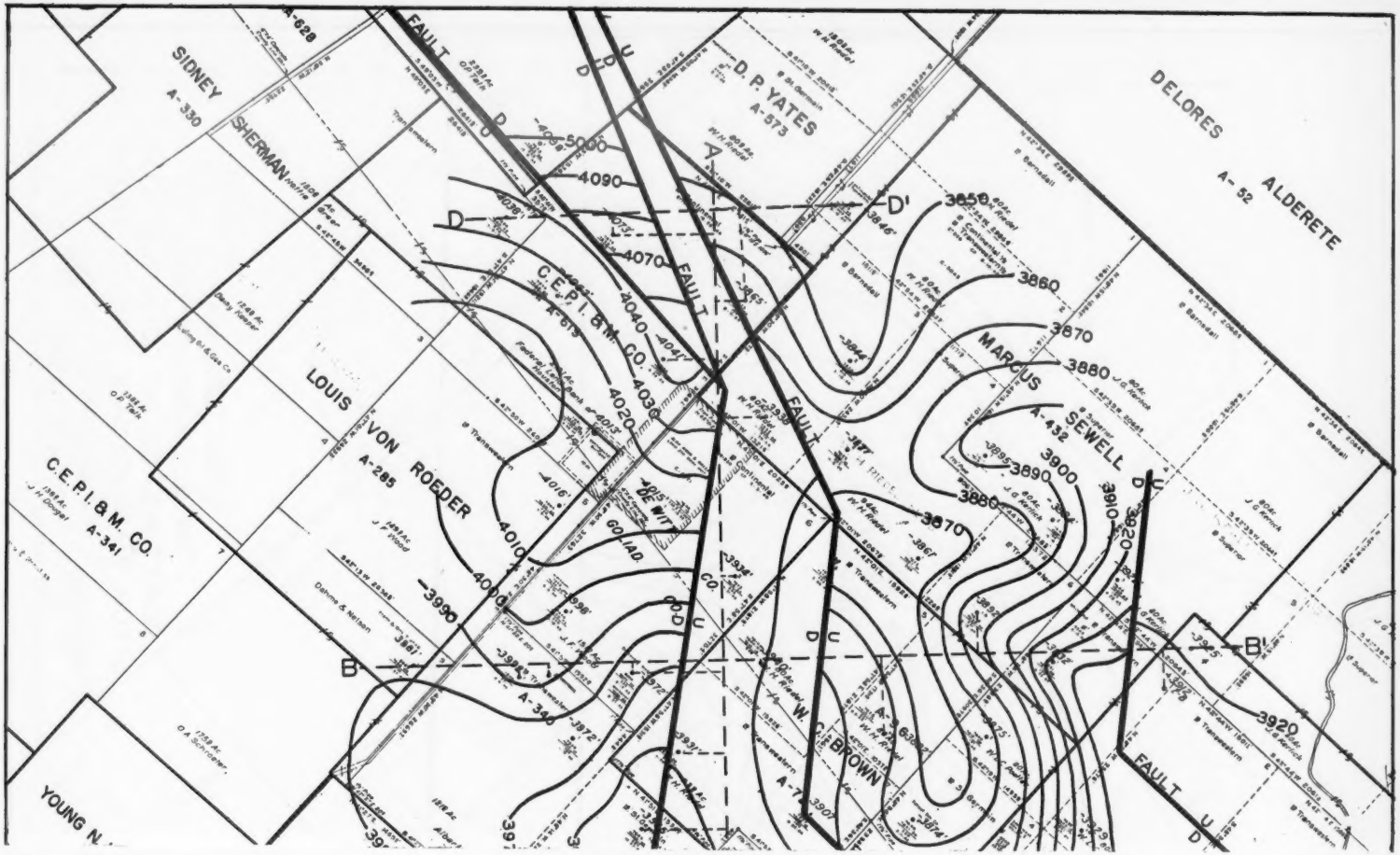
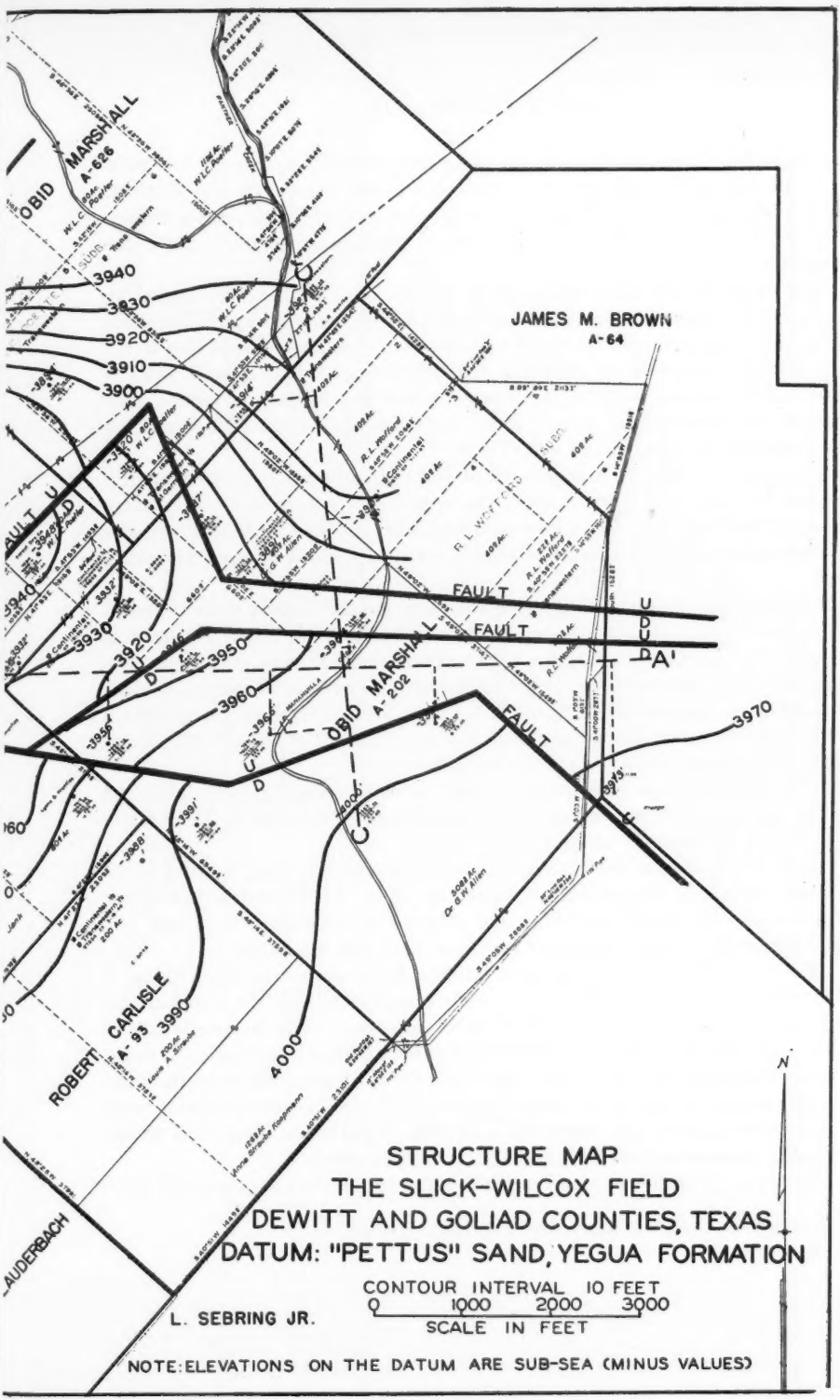


Fig. 5.—Structure map on



"Pettus" sand, Yegua formation.

placement both horizontally along its strike and vertically up the section, indicates the fallacy of attempting to consider the faults as separate and distinct. Rather, they should be considered, as was pointed out previously, as the boundaries of a fault zone where many minor faults combine to make the major displacement.

The values of the throw of each fault and the total displacement caused by the fault zone, vary with depth, generally decreasing somewhat upward through the section. This indicates that faulting took place at different times with recurring structural movements. Although the evidence for this surmise is masked somewhat by the fact that the displacement generally took place along the same zones of weakness or fault planes, corroboration may be obtained by studying cross sections *CC'* (Fig. 8) and *BB'* (Fig. 7).

In section *CC'* (Fig. 8), it may be noted that the westernmost fault apparently dies out and can not be traced above the uppermost Jackson beds. This places the age of this fault in upper Jackson or lower Vicksburg time. At least it indicates that movement along this fault surface ceased after Jackson or early Vicksburg time.

In section *BB'* (Fig. 7), the easternmost fault does not extend to the Carrizo-Wilcox beds dying out in the upper Mt. Selman beds. Thus, it appears that this younger faulting occurred with the recurrent structural movements in later geologic time. The older and more deeply buried beds were rendered more competent or more plastic by the weight of the beds above them. Therefore these beds did not fracture, but were warped or domed upward as a result of the same structural forces that caused the faulting in the beds above them.

This decrease in the competency of beds at shallower depth is also reflected by the splitting of the major faults in the upper parts of the section. This greatly complicates the structure in the younger beds.

Some of the faulting must have occurred in post-Goliad time in order to obtain the anomalies mapped at the surface by Sturm. Stein[15] states that in this area many of the faults that affect the Wilcox can be mapped from core-drill data obtained in shallow wells that reach the basal Oakville sands.

The down-dropped block shown in sections *BB'* (Fig. 7) and *DD'* (Fig. 9) is of interest. Its location can be be accurately mapped by using the Vicksburg (?) or basal Frio sand as a datum. Stein[16] states that this type of faulting is typical of the area and has resulted in commercial accumulations of oil in numerous fields, notably the Pettus field in northern Bee County. The oil accumulates on the down dip and basinward side of the major fault but is trapped against the fault block which is downthrown with respect to both sides of the major fault. This affords an updip, counter-inclined fault seal and an excellent trap.

The east-west strike or trend of the faulting in the Slick area appears to be

[15] I. H. Stein, personal communication, Alice, Texas (April, 1947).

[16] *Ibid.*

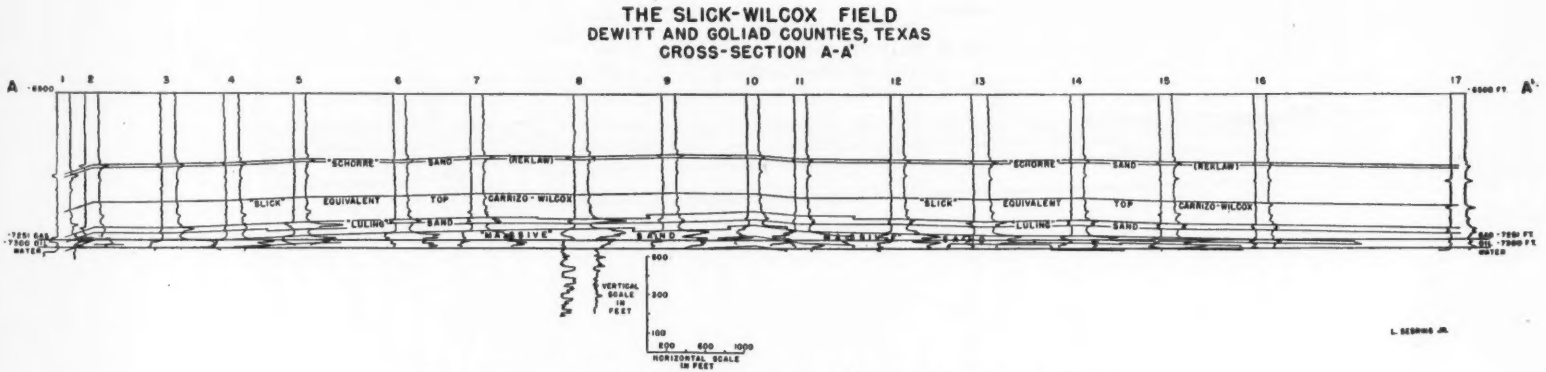


FIG. 6.—Cross section *AA'*, extending from west to east along long axis of structure.

Well Number on Cross Section

1. Continental Oil Company and Sunray Oil Corporation's W. H. Riedel 1
2. Continental Oil Company's Federal Land Bank of Houston 5
3. Continental Oil Company's Federal Land Bank of Houston 3
4. Continental Oil Company's Federal Land Bank of Houston 2
5. Barnsdall Oil Company's W. H. Riedel 1
6. Continental Oil Company's Federal Land Bank of Houston and Alda S. Wood 1
7. Continental Oil Company's Alda S. Wood 2
8. Continental Oil Company's Alda S. Wood 1
9. Sunray Oil Corporation's W. H. Riedel 1
10. Lyons and Prentiss' Albert S. Jank 1
11. Continental Oil Company's G. W. Allen 1
12. Continental Oil Company's G. W. Allen 5
13. Continental Oil Company's G. W. Allen 4
14. Continental Oil Company's G. W. Allen 2
15. Continental Oil Company's G. W. Allen 6
16. Continental Oil Company's G. W. Allen 8
17. Phillips Petroleum Company's Kraege 1

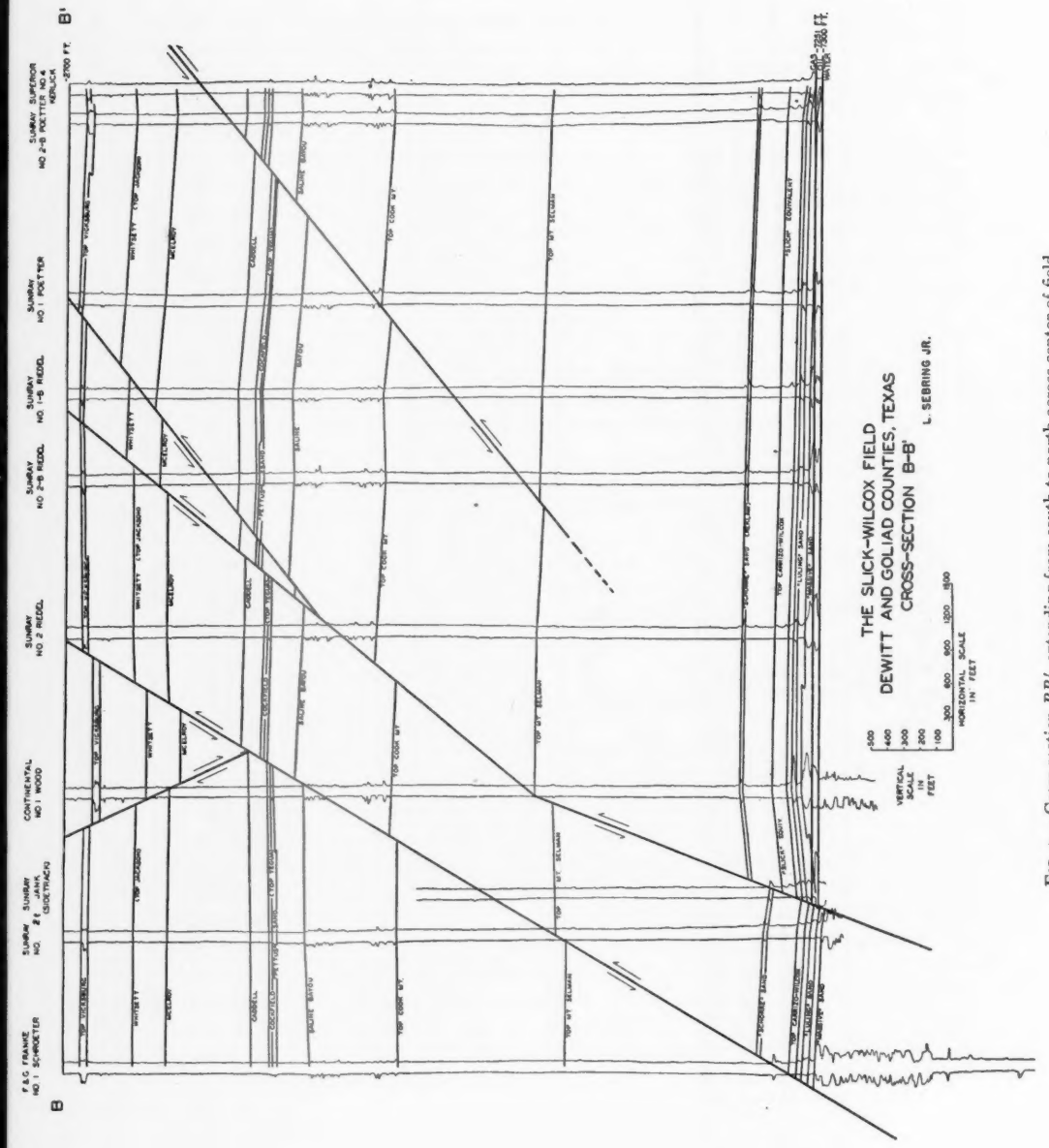


FIG. 7.—Cross section *BB'*, extending from south to north across center of field.

significant. Other Wilcox fields in the area located on the same side of the same fault zone, producing from the same sand, and showing as much structural closure, but located where the fault zone trends northeastward, have produced only moderate amounts of oil as compared with amounts at the Slick-Wilcox field. The comparatively excellent accumulation at Slick may be caused by this basinward bend in the faulting which could place the reservoir beds in a more favorable relationship to their source beds.

The structural maps of the Slick-Wilcox field suggest that the structure was caused by deep-seated vertical movements, possibly by upwarping over a deep-seated salt dome.

DRILLING AND PRODUCTION

DEEP PRODUCTION

The drilling in the Slick-Wilcox field was done with heavy steam-powered rotary rigs, generally equipped with 3 boilers and 127-foot or 136-foot derricks. Natural gas was used as fuel. The rigs were equipped with heavy blowout preventors, a common and necessary operating practice in the district.

Both natural and commercial muds were used in drilling the wells. The average density of the drilling mud used was 9 pounds per gallon, and the operators were careful to maintain their drilling fluids at this weight when the producing sand was encountered.

A surface string of $10\frac{3}{4}$-inch O.D. casing was set just above the basal Oakville sands. Length of this string is generally slightly over 1,200 feet. The long string was ordinarily set on the bottom of the hole and gun-perforated at the desired depth. The Sunray used $5\frac{1}{2}$-inch O.D. casing and the Continental used 6-inch O.D. casing for the long string.[17]

The oil is produced through 2-inch tubing usually set a few feet above the perforations. As there is a gas cap present and the field is also under a water drive, care was taken to perforate in the part of the section containing the oil saturation. As previously pointed out the initial oil-water level was at −7,300 feet in the "Massive" sand and the initial oil-gas level was at −7,251 feet in the same sand. Sunray engineers[18] estimate the present oil-gas level at −7,260 feet and the oil-water level at −7,290 feet. Continental engineers[19] estimate the present oil-gas level at −7,255 feet and the oil-water level at −7,295 feet. There is a 5-foot discrepancy between these estimates, but they both indicate that the field is producing under the drive of encroaching water and an expanding gas cap. These are ideal producing conditions and a high percentage of the oil in place should be recovered.

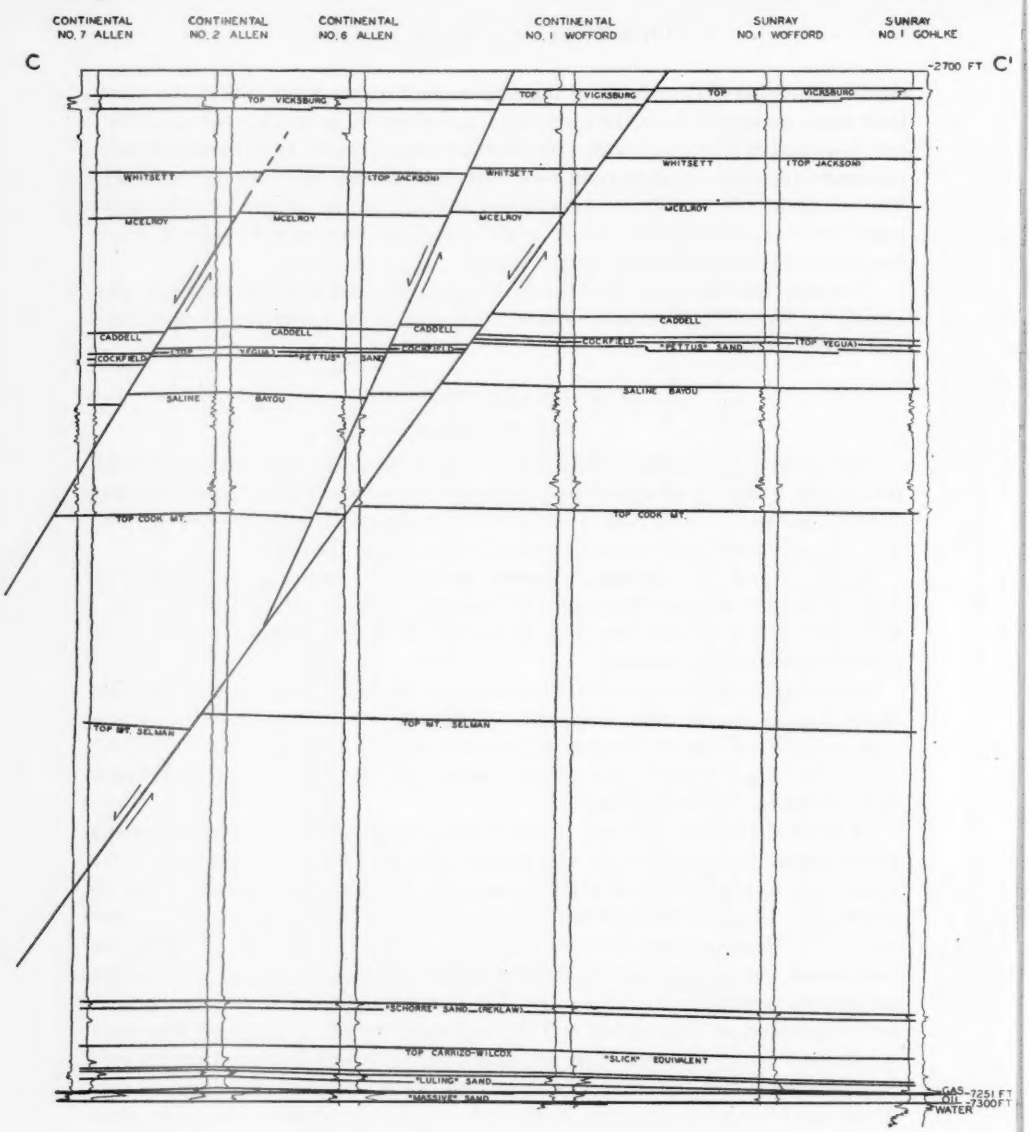
The initial gas-oil ratio ranged from 439:1 (439 cubic feet of natural gas per barrel of oil produced at standard conditions) for the discovery well to 1195:1

[17] C. E. Wilson, personal communication, Alice, Texas (April, 1947).

[18] D. O. Chapell, letter dated May 9, 1947.

[19] W. H. Rosser, letter dated May 9, 1947.

FIG. 7.—Cross section *BB'*, extending from south to north across center of field.



THE SLICK-WILCOX FIELD
DEWITT AND GOLIAD COUNTIES, TEXAS
CROSS-SECTION C-C'

L. SEBRING JR.

VERTICAL SCALE IN FEET: 500, 400, 300, 200, 100

HORIZONTAL SCALE IN FEET: 300, 600, 900, 1200, 1500

FIG. 8.—Cross section *CC'*, extending from south to north along eastern edge of field.

for the Continental's Federal Land Bank of Houston No. 2. Most of the wells had an initial gas-oil ratio ranging from 550:1 to 750:1. In March, 1947, the gas-oil ratio on Sunray leases ranged from 660:1 to 2,438:1. Only one well had a gas-oil ratio of more than 2,000:1 (maximum gas-oil ratio allowed by the Railroad Commission without penalty), and most of them had ratios of approximately 800:1. The relatively low increase in the gas-oil ratio since the field was discovered indicates that most of the wells were completed properly and that the field has been operated efficiently so that the maximum recoverable oil will be realized.

During March, 1947, Sunray leases[20] produced 20,136 barrels of water while producing 62,235 barrels of oil. Most of the water was produced from one well, the O. P. Talk No. 1. This is an edge well and it was once unsuccessfully worked over in an attempt to squeeze off the water. In the same period, Continental's wells, fewer in number and generally located higher on the structure with fewer edge wells, produced 14,260 barrels of water.

Work-over operations have been carried out in some wells with variable success. These operations are commenced in an attempt to lower water production, to lower the gas-oil ratio, or to increase the permeability by acidizing. The first two operations are done by squeezing the well with cement or plastic and then re-perforating the casing at a more suitable depth in the producing zone.

To date, 48 wells have been successfully completed as producing oil wells in the field. Of these, 11 were completed in 1943, 29 in 1944, and the remainder in 1945. The wells were drilled on 40-acre tracts with a minimum distance of 900 feet between wells and 330 feet from a lease line. It required an average of 70 days to complete a well at a cost between $65,000 and $70,000 per well completed in the tanks.[21]

The initial bottom-hole pressure was 3,360 psi. Sunray wells had an average bottom-hole pressure of 3,190 psi on February 1, 1947, while Continental wells had an average bottom-hole pressure on the same date of 3,204 psi. The average of these two values is 3,197 psi. As these two operators control most of the production in the field, this figure should be representative for that date. This figure indicates a pressure decline of 163 psi since the field was discovered.

The field had produced 4,074,272 barrels of oil to February 1, 1947, or 24,995 barrels of oil per pound of pressure drop.

The Spurlock Pipe Line purchases all of the oil produced in the field.

As there are no facilities for using the natural gas produced with the oil, it is now vented to the air.

The March, 1947, allowable was 116 barrels of oil per well per producing day. The price of the crude which averages a gravity of 35° A.P.I. was $2.08 per barrel.

[20] C. E. Wilson, personal communication, Alice, Texas (April, 1947).

[21] I. H. Stein, "The Slick Field, DeWitt and Goliad Counties, Texas," unpublished paper given before the Corpus Christi Geological Society, Corpus Christi, Texas (1944).

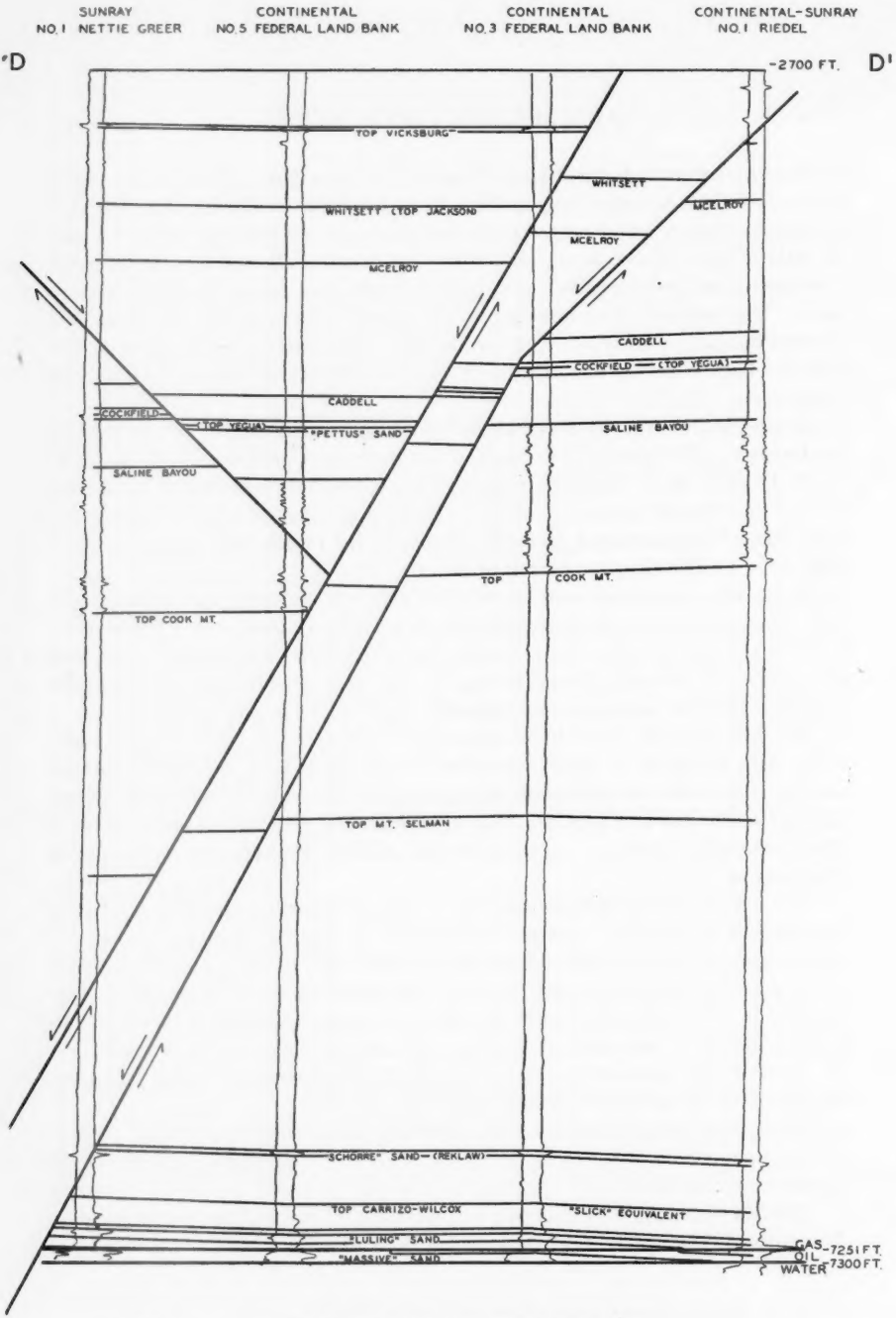


FIG. 9.—Cross section *DD'*, extending from south to north along western edge of field.

The field by the end of March, 1947, had produced 4,339,599 barrels of oil from an estimated original recoverable reserve of 20 million barrels (Sunray and Continental engineers concurred in this estimate).[22,23]

SHALLOW PRODUCTION

In his report to the Slick Estate, Swiger places the average cost of completing and equipping the shallow "Pettus" wells at $15,000. The average price obtained per barrel of oil was $1.00.

In the T. B. Slick Estate's Poetter No. 1 drilling report, the following completion data were recorded.

> Set 21 feet Layne and Bowler Screen and 2 joints of blank liner. Texas type set-shoe, back-pressure valve, lead shoe and packer.

No other production data are available, and as all of these shallow wells have been long abandoned, there is little profit in discussing them. It should be noted, however, that the Slick Estate's Poetter No. 1 had produced 53,982 barrels of 48.6° A.P.I. oil to September 1, 1933, this single well providing almost all of the 69,270 barrels of oil that the field produced before 1937.[24]

FUTURE DEVELOPMENT

There are good possibilities of future deep production in the field if the basal Wilcox sands are present and have favorable porosity and permeability. The writer knows of no wells on the same strike as the Slick-Wilcox field which have penetrated to the Midway.

The thickness of the Carrizo-Wilcox section at Slick is not known. At Falls City in Karnes County, a considerable distance updip, the Southern Minerals Company has production from 13 sands ranging from the middle of the Carrizo-Wilcox to 300 feet above the Midway-Wilcox contact. In this area, the Carrizo-Wilcox thickness is approximately 3,200 feet, and at Slick the beds should be considerably thicker. A deep test exploring the possibilities of the basal Wilcox sands would necessarily be drilled some distance below 10,000 feet.

A well to test the basal sands on top of the structure should be located southeast of the present field, possibly at the north end of the Straube Farm, Robert Carlisle Survey, No. A-93.

Shallower possibilities for new production may lie in the development of wells in the "Pettus" sand. As previously noted, Stein[25] stated that where the "Pettus" lies against a counter-inclined fault, a commercial accumulation of oil commonly occurs. This condition is present on the western edge of the field (auxiliary fault on structural map of "Pettus," Fig. 9, and cross section *DD'*, Fig. 7).

[22] D. O. Chapell, letter dated May 9, 1947.

[23] W. H. Rosser, letter dated May 9, 1947.

[24] R. B. Swiger, *Report on the Slick Field, Goliad and DeWitt Counties, Texas*, for Trust Estate of T. B. Slick (September 25, 1933).

[25] I. H. Stein, personal communication, Alice, Texas (May, 1947).

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MARINE SEDIMENTATION AND OIL ACCUMULATION. II. REGRESSIVE MARINE OFFLAP AND OVERLAP-OFFLAP[1]

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ABSTRACT

The marine regression, its resultant stratigraphic marine "offlap" and the compound features "overlap-offlap," "offlap-overlap" that result from the alternation of transgression and regression are discussed.

Although sands deposited in a regressive sea are not considered as favorable, theoretically, as the overlying transgressive sands for the trapping of petroleum, local structural and environmental conditions may effect excellent reservoirs.

INTRODUCTION

The Tertiary history of the Gulf Coastal Plain has been recorded in the sediments deposited during the alternating advances and retreats of the Tertiary Gulf of Mexico. In a previous paper[4] the writers discussed the stratigraphic features resulting from a marine transgression, and the relation of the marine transgressive overlap to petroleum accumulation. This paper presents both a study of the marine regression, with its resultant stratigraphic sequences, the marine "offlap" or "marine regressive overlap," and a discussion of the compound features resulting from the alternation of transgression and regression, the "overlap-offlap" and the "offlap-overlap." The sedimentation and its relation to petroleum accumulation are discussed under ideal conditions only, without reference to the effects of structure.

MARINE REGRESSION

By regression is meant the retreat of marine waters accompanied by seaward migration of the shore margin. During a regression the sea "laps off" older sediments, depositing successively younger sediments as it retreats, each succeeding stratum being younger than, and having less landward extent than, the underlying stratum. Traversing these beds in a landward direction one would find progressively older beds exposed. Hence the term "marine offlap" is applied to the series of sediments deposited during a retreat of the sea. Grabau[5] has also termed this stratigraphic feature a "marine regressive overlap"; but since the word "overlap" implies the complete covering of older sediments by younger beds, the writers prefer to use "offlap."

[1] Manuscript received, December 3, 1947. Published by permission of Shell Oil Company, Inc.

[2] Shell Oil Company, Incorporated.

[3] Pond Fork Oil and Gas Company.

[4] Doris S. Malkin, and Dorothy A. Jung, "Marine Sedimentation and Oil Accumulation. I. Transgressive Marine Overlap," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 11 (November, 1941), pp. 2010–20.

[5] A. W. Grabau, *Principles of Stratigraphy*, 2d ed., p. 734. New York (1924).

As has been pointed out in the discussion of the transgressive marine series, the sea and the land in an effort to attain an isostatic equilibrium are never in completely stable relationship. The sea areas of the world constantly strive to encroach upon the land, but for one or several of many causes must withdraw at intervals. Such retreats may occur locally or regionally, as minor fluctuations or major withdrawals, causing stratigraphic features identifiable by a study of the sequence and types of sediments. In discussing theoretically the transgressive and regressive seas of the Gulf Coast Tertiary, their respective deposits may be defined separately as to causes, magnitudes, fossil horizons, and sedimentation; but it is obvious that, practically, transgression merges into regression, making a complete stratigraphic series.

Broadly speaking, the marine offlap differs from the progressive marine overlap in that the former is a series of sediments laid down in a retreating sea, the latter in an advancing sea. The offlap is similar, however, to the overlap, in that both may be caused either by eustatic, isostatic, or epeirogenic adjustment, or by variations in the supply of detritus.

The causes have been discussed[6] but are reviewed briefly. The eustatic, isostatic, or epeirogenic movements which cause elevation, warping, or tilting of an adjacent landmass result in the deposition of an offlapping series of sediments as more of the area which was previously covered by marine waters is elevated and becomes land area. Elevation of the landmass supplies an increased quantity of detritus which in turn may push the sea farther out. The lithologic character of the sediments is determined by their source and the rate of movement.

Decrease in the rate of subsidence, or temporary cessation of subsidence, of the marine basin may be accompanied by an increase in the quantity of detritus and thus cause a retreat of the sea. Likewise, climatic changes resulting in more rapid fluviatile erosion and increased deposition of detritus may drive out the sea.

From the structural history of the Gulf Coast, it may be inferred that the several regional regressions of the Gulf of Mexico can be attributed largely to increases in the amount of detritus which accumulated near the shore margin because of change in the rate of subsidence rather than to uplift or oscillation of the adjacent landmass or of the basin. Many local regressions are referable to such causes excepting in cases where there is definite structural evidence to the contrary, that is, major flexures or faults. A similar interpretation of the Cretaceous deposits in the southern San Juan basin, New Mexico, has been published.[7]

[6] D. Malkin and D. A. Jung, *op. cit.*

[7] J. D. Sears, C. B. Hunt, and T. A. Hendricks, "Transgressive and Regressive Cretaceous Deposits in Southern San Juan Basin, New Mexico," *U.S. Geol. Survey Prof. Paper 193-F* (1941), pp. 102–05. "According to this concept, the formation of transgressive and regressive deposits depends upon relative rates of sinking and of sedimentation. When sinking predominates, there is transgression; when sedimentation prevails, regression and regressive deposits are the result. Any increase or decrease in the rate of supply of debris merely has an effect equivalent to that of some decrease or increase, respectively, in the rate of subsidence. For the sake of simplicity, therefore, in this paper the rate of supply of debris is assumed to be constant, and the emphasis is put on the rate

In either case[8]

As the retreat of the sea from the land may under normal conditions be considered a process occupying a greater or less amount of time, it is evident that deposition at a distance from the shore need not be interrupted. Thus, while within the zone of retreat for any given time period, no sedimentation will occur, such sedimentation may, nevertheless, go on at a regular rate beyond this zone. In other words, a certain thickness of offshore deposits must be considered the depositional equivalent of a given time period, which in the shore zone is represented by a given amount of retreat. Thus, it is brought about that each successive formation of the retreatal series extends shoreward to a less extent than the preceding one. As each formation or bed passes shoreward into a coarser clastic it is evident that the shore ends of all the formations deposited during the retreat will together constitute a stratum of sandstone or conglomerate which in age rises seaward, since in that direction it is progressively composed of the ends of higher and higher formations.

At the contact of land and sea the coarse clastics or sands are deposited, grading seaward into finer and finer sediments, consisting of sands, sandy shales, shales, and muds. Thus as the sea progressively retreats the sandy phases will be carried farther and farther seaward. The sands overlying the sandy shales and the sandy shales overlying the shales are lithologic units and may be alike within themselves in regard to their type of materials and size of grain. The lithologic units are not, however, synchronous (Fig. 1); yet any one facies or lithologic unit may be homo-

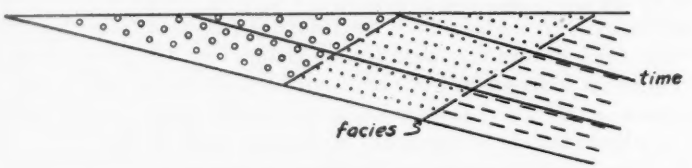

FIG. 1.—Diagrammatic interpretation of "offlap" sediments laid down during marine regression, showing sand rising stratigraphically downdip.

taxial; in other words, it may contain the same faunal assemblage wherever it is found. Equivalent time zones may be correlated in different facies by faunal distribution studies, ecologic studies, range charts, and the recognition and interpretation of cosmopolitan faunas. As the sea retreats and marine sediments become covered by deltaic, lagoonal, fluviatile, and continental material, a given species may be exterminated in a near-shore locality and continue to exist farther away from the shore where a more favorable environment persists. Therefore the top of a paleontologic zone may not be contemporaneous in all places.

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of subsidence. . . . Eventually, however, the subsidence of the land and the deepening of the sea, though still continuing, gradually slowed down to a considerably lower rate. If the supply of sediment continued unabated, there came a time when its deposition began to gain on the sea, which then could no longer encroach on the land, but on the contrary was gradually pushed backward by a slow outward growth of the near-shore deposits. The several zones of deposition began a slow march seaward, each zone in turn leaving its typical deposits above those of the zone that had retreated."

[8] A. W. Grabau, *op. cit.*, p. 734.

COMPOUND FEATURES

The marine retreat may be regarded as an interruption in the constant encroachment of sea overland. A retreat, therefore, is always followed by an advance; and the regressive deposit grading seaward from coarse to fine clastics is overlain by a transgressive deposit in which each successively younger layer is carried farther inland. The resulting stratigraphic feature, a compound sand wedge between two marine shale phases is called the "offlap-overlap." The sand wedge is thickest updip and wedges out, gradually disappearing or "shaling up" downdip (Fig. 2).

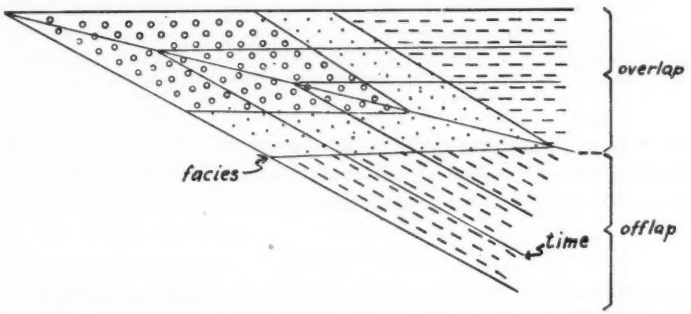


FIG. 2.—Diagrammatic interpretation of "offlap-overlap" sediments laid down during marine regression and transgression, showing sand wedge "pinching out" downdip.

The "overlap-offlap" is the reverse compound feature. It is deposited when an advancing sea lays down its characteristic deposits, followed by a retreat of the sea with its characteristic deposition. The overlap-offlap is recorded in the stratigraphic column as a shale wedge pinching out shoreward as it grades into coarser sediments, and limited above and below by sandy phases which pinch out seaward (Fig. 3).

The processes of sedimentation during successive transgressions and regressions of the sea are continuous. Minor interruptions, commonly in near-shore places, result in a hiatus, or an absence of deposition (and of erosion as well) where a profile of equilibrium has temporarily been reached. By its very nature, a hiatus must have a downdip depositional equivalent. Even if near-shore sedimentation is interrupted long enough under conditions which permit subaerial erosion to take place the resulting disconformity is the equivalent in time to sedimentary deposits seaward. Obviously the presence of a surface disconformity does not insure one in the subsurface. Conversely, as in the case of the "*Heterostegina* wedge" and in many other instances which have come to light since the advent of subsurface geology, an apparently complete surface section may have large time intervals represented in it by planes, rather than by thicknesses of

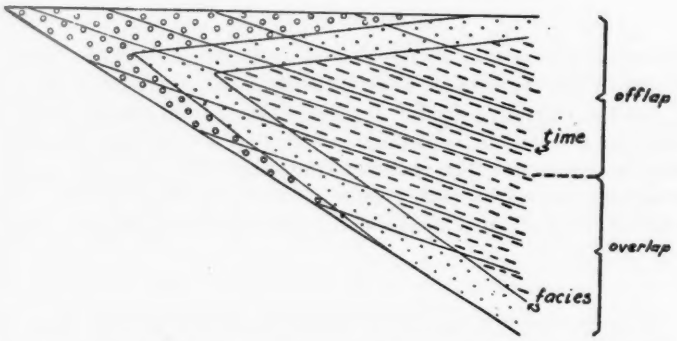


FIG. 3.—Diagrammatic interpretation of "overlap-offlap" sediments laid down during marine transgression and regression, showing shale wedge "pinching out" updip.

sediments. H. B. Stenzel[9] has shown that the magnitude of a disconformity may be estimated by comparison of the evolutionary development of a particular group of fossils above and below the absent strata.

EXAMPLES

Any picture of the Gulf Coast Tertiary is of necessity a composite of many overlaps and offlaps; and it is practically impossible empirically to draw an exact boundary between a transgressive and a regressive sequence, because one merges into the other.

From the electrical-log section in Figure 4[10] an interpretation of the stratigraphy of western Louisiana in terms of its sedimentary history can be made. The diagram shows the several sand wedges (Wilcox, Sparta, Yegua, Frio, and Miocene) formed by the transition upward of regressive sands into basal transgressive sands; and the shale wedges (Cane River, Cook Mountain, Jackson, "Marine upper Oligocene," and lower Miocene), representing marine deposition between the transgressive and regressive sands. The sand wedges pinch out downdip, passing seaward into shale. The shale wedges thicken downdip, pinch out updip grading into sands and non-marine sediments.[11]

An example of the offlap series formed during a regression, and of the compound offlap-overlap is the Wilcox group of sediments. A study of the deposition

[9] H. B. Stenzel, *Bull. Geol. Soc. America*, Vol. 51, No. 12, Pt. 2 (1940), p. 1949.

[10] Modified from cross section No. 6 by R. A. Copeland and M. A. Reasoner, in "Study of the Wilcox Group," Houston Geological Society, June, 1940.

[11] Local sand lenses and "pinch-outs" representing off-shore bars and barrier beaches, features commonly associated with a shore line of emergence, are not treated in this paper. A comprehensive study of lens-type sedimentary traps is included in "The Importance of Stratigraphic Traps in Petroleum Geology," by A. Herrere Ducloux, *Mines Magazine*, Vol. 31, No. 9 (September, 1941), pp. 461–62.

at the close of Midway and beginning of Wilcox time indicates the nature of the transition from transgression to regression. Toward the close of the Midway the Wilcox regression began, the Gulf shoreline began to move seaward and the characteristic Midway sedimentation of fine silts and clays was followed by regressive, offlapping deposits of coarser marine detritus and, later, the fluviatile and deltaic material of the Wilcox.

LeBlanc[12] has correlated the upper Midway faunas of Louisiana. He states that of the lower 800 feet of "Wilcox" below the *Ostrea thirsae* zone, the upper 300 feet contains a very limited fauna; the lower 500 feet of sediments carries a varied fauna which is older than basal Wilcox of Texas and may be correlated with the upper Midway transitional faunas of the Naheola formations of Alabama and with the Kerens member of the Wills Point (upper Midway) of Texas. This correlation confirms the interpretation of the closing history of the Midway as regressional. Apparently the change in sedimentation in Texas at the close of Midway time resulted in a more abrupt faunal change in Texas than in Louisiana, where Midway-type faunas were able to persist through a long period of Wilcox deposition. The upper Midway Gulf probably withdrew southeastward from Texas. The lower Wilcox represents transitional deposition in a retreating Midway sea. The lithologic change from Midway to Wilcox, without apparent unconformity, and the concomitant faunal variations may have taken place because of (1) cessation of crustal stability, (2) climatic change causing increase of detritus, or (3) a decrease in rate of subsidence of the Gulf basin relative to the rate of deposition. In any case an increase in detrital material would result. Probably either or both of the two latter conditions produced the lithologic changes and caused the retreat of the Midway sea. The absence of marked unconformity tends to preclude the possibility of crustal instability as a cause for the retreat.[13]

By the end of the Wilcox regression (roughly middle Wilcox time) the sea had withdrawn to a position probably many miles seaward from the present Gulf shoreline.

> and a belt of the Gulf Coast at least 100 miles wide from north to south along the whole length of the strand line became a low, gently inclined coast[14]

whose surface represented the top of the regressive or offlapping sand (progressively younger seaward). On this surface, concurrently with the retreat of the sea, were being deposited the sands and clays of an

> epoch of nearly continuous river and marsh sedimentation brought to a close only when the waters of the Gulf transgressed and brought with them the marine sands, marine

[12] R. J. LeBlanc, "Correlation of Upper Midway Fauna of Louisiana" (abstract), *Program Amer. Assoc. Petrol. Geol.*, 26th annual meeting (1941), p. 40.

[13] J. D. Sears *et al.*, *op. cit.*

[14] E. H. Sellards *et al.*, "The Geology of Texas, Vol. 1, Stratigraphy," *Univ. Texas Bull. 3232* (1933), p. 591.

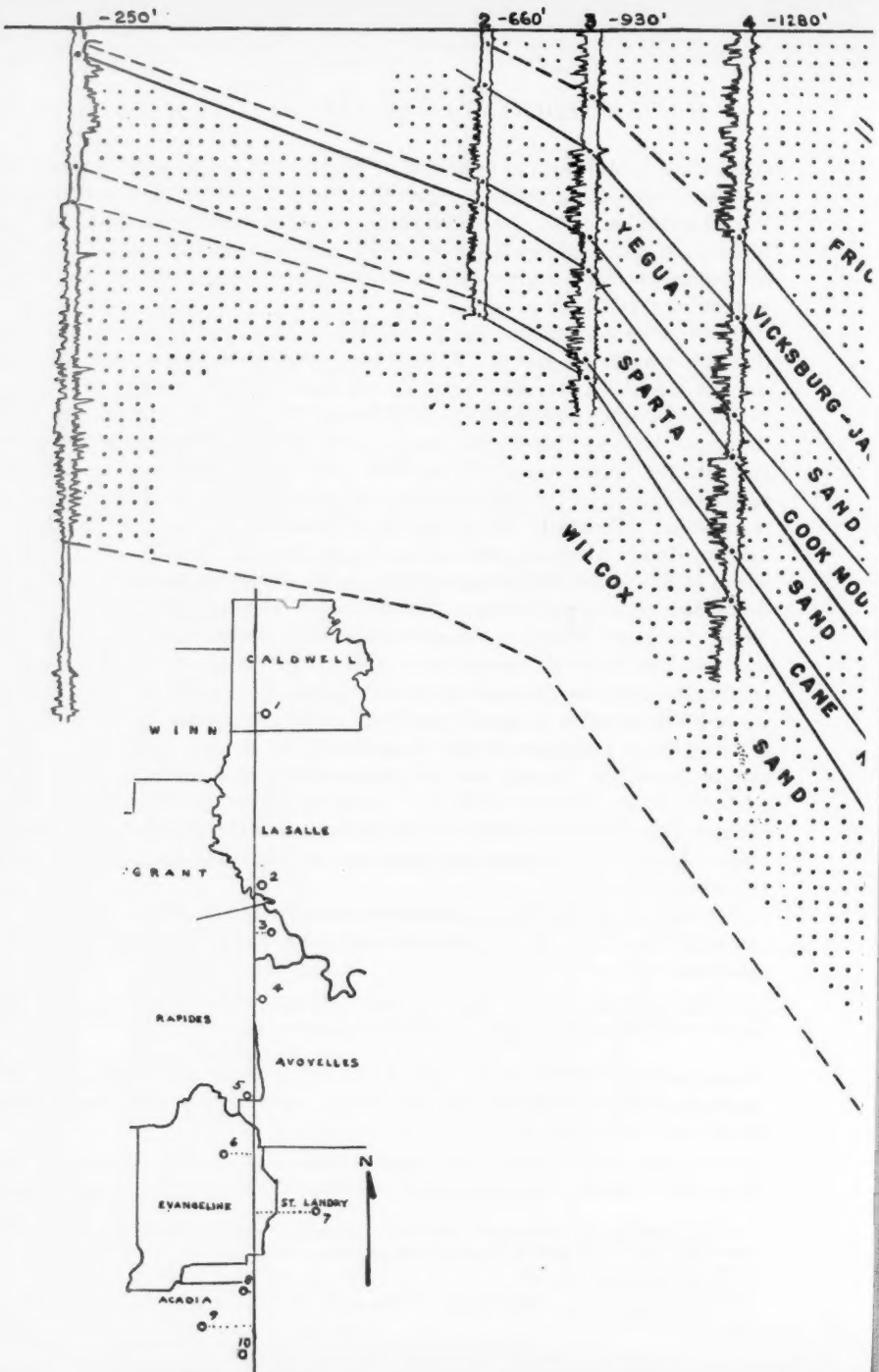
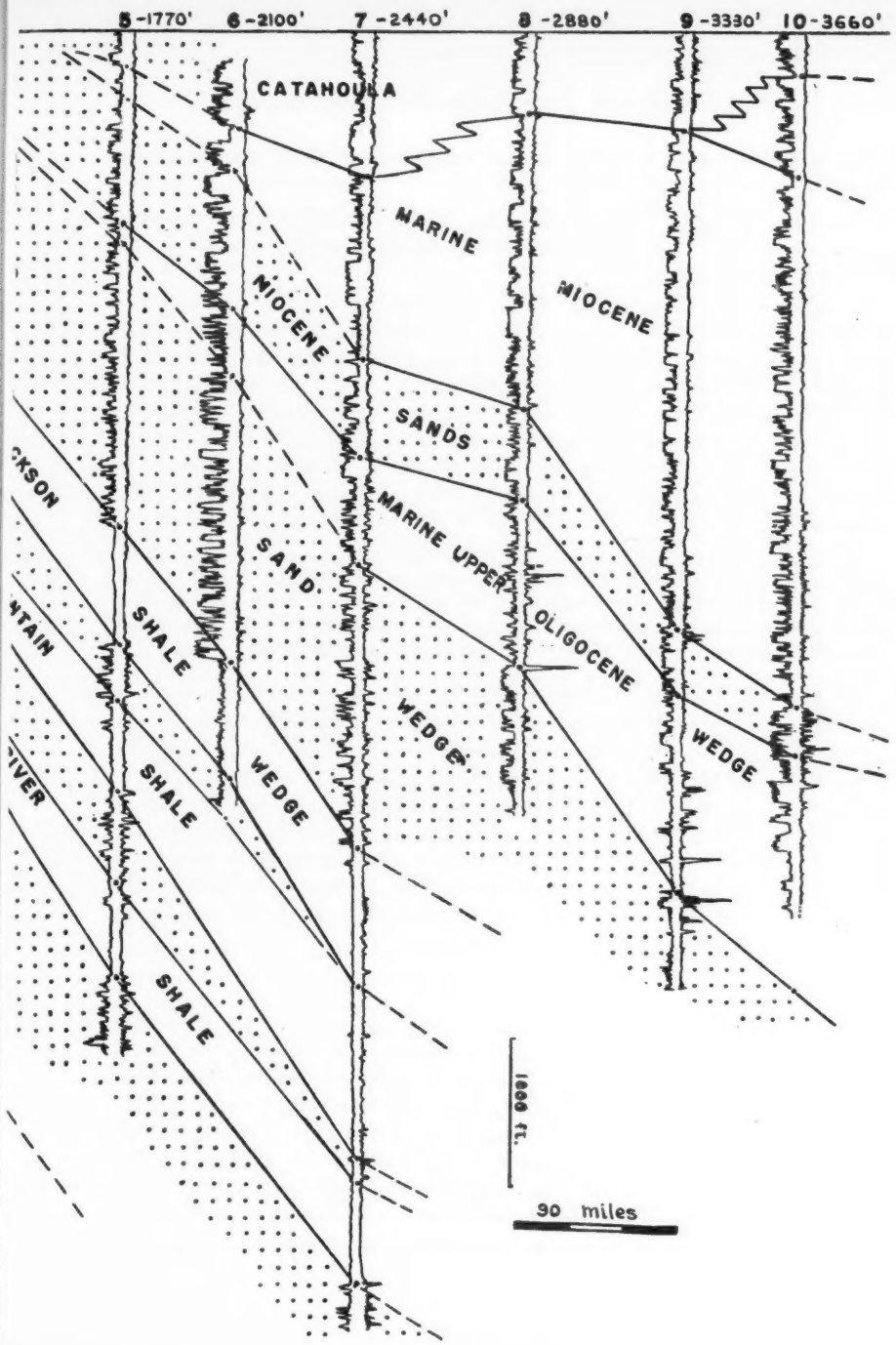


FIG. 4.—Electrical-log dip section, west-central Louisiana, modified from cross section No. 6, and logs redrawn from a hypothetical datum. The correlation lines delineate the boundaries of the Co., Louisiana Central Lumber Co. No. 1; (2) Kirby Petroleum Co., Goodpine Lumber Co. No. 1; Richardson, Weil Co., Inc. No. 1; (6) Louisiana Crusaders, Hess No. 1; (7) Herton Oil Co., Thistle-Arceneaux No. 1; (10) Humble Oil and Refg. Co., Nordyke No. 1.



in "Study of the Wilcox Group," Houston Geological Society, June, 1940; horizontal scale changed, shale and sand wedges; paleontologic correlations are not shown. Logs used: (1) Arkansas Fuel Oil (3) C. L. Decker, Lee Lumber Co. No. 1; (4) C. B. Bunte, Hines Tie and Timber Co. No. 1; (5) waite Lumber Co. No. 1; (8) Superior Oil Corp., Adam Smith No. 1; (9) Superior Oil Corp., J. S.

bedding, and marine fossils of the Sabinetown formation toward the close of the Wilcox period.[15]

The Rockdale or middle Wilcox sand wedge, whose downdip extent or seaward pinch-out is not yet known, is an offlap-overlap deposit, formed by the retreat and advance of the Wilcox sea.

An example of the sand wedge, or offlap-overlap, more readily seen than the Rockdale is the Sparta sand in the middle Claiborne. Drilling has penetrated this formation at both its surface and downdip limits. Paleontology, sample logs, and electrical logs have recorded sufficient information for ascertaining exactly the downdip limits of this sand wedge and it is possible to draw a line roughly parallel with the present coast line where the last remnants of the sand deposit will be encountered. The history of the deposition of the Sparta sand as described in University of Texas *Bulletin 3232*[16] is evident both from the surface and the subsurface strata.

> The basal sands were laid down on a beach and coastal plain in conjunction with the withdrawal of the Weches sea. The middle sands are mainly fluviatile deposits spread broadly over a flat terrain. The upper sediments were deposited along a transgressing shoreline laid down in advance of the Crockett sea and were worked over by later marine waters. Strata of such an origin wedge out seaward and expand landward.

A marine shale wedge, or overlap-offlap, is typically exemplified in the "upper Oligocene" (*Discorbis-Heterostegina-Marginulina*) marine series (Fig. 4).

The transgressive marine sands of the upper Frio-*Marginulina* are overlain by the *Heterostegina* shales, which are in turn overlain by the *Discorbis* zone deposited in the beginning of the regression that brought about the deposition of the overlying Miocene sands. Part of the marine section may be represented updip by a hiatus or complete lack of deposition in a belt between the actual continental and marine deposition. Not only thickening of the shale wedge downdip, but the absence of beds updip because of non-deposition may be deduced from a detailed study of electrical logs in a given area.

ECONOMIC ASPECTS

Many marine shale wedges of small magnitude are present in the subsurface, and represent minor marine invasions. For example, they occur in the Wilcox, in the Yegua, in the Frio, and in the Miocene. In many places these shale wedges make possible the trapping of oil in small transgressive marine sands within a typically non-marine section. Oil is generally not found in the regressive sands, but in the overlying transgressive sands of the sand wedges. This fact is illustrated in the Gulf Coast by the large percentage of productive sands which are transgressive in origin. Where the regressive sand is immediately overlain by a transgressive sand, the oil which has accumulated has migrated into the over-

[15] E. H. Sellards, *op. cit.*, p. 592.

[16] E. H. Sellards *et al.*, *op. cit.*, p. 654.

lying sand. In the event, however, that a regressive sand far enough downdip is overlain by marine shale it is possible that some oil may accumulate and be trapped. Specialized structural or sedimentary conditions would serve also to permit oil to accumulate in updip regressive and non-marine sands.

Although most Gulf Coast oil fields are in general attributed to structural anomalies it is evident that the reservoir sands are the results of deposition in an oscillating Tertiary sea. These sands may have been deposited prior to, during, or after structural movement. In many cases interpretation of the sedimentary history in oil fields not only establishes productive limits of sand lenses but ties down the time of movement and thus indicates whether or not hydrocarbons may have been trapped.

For lateral continuity in a regional picture, datum planes for contouring are necessary for correlating the paleontologic data. Information derived from wells has established valid subsurface markers in updip and downdip areas. Vertical variations, however, do occur and in the previous paper on marine transgressions[17] some examples were cited. *Nonionella cockfieldensis* which lived during the close of the Cockfield transgression was used to illustrate a foraminifer occurring in different facies at the same time. In the updip phases the fossil was found in the sand; traced downdip it was found occurring higher and higher in the section above the sand. A line connecting the occurrences represents a time plane, whereas the sand is progressively younger updip. In the regressive sand deposits the reverse is true. A "time fossil" will be found lower and lower in the section below the sand as it is followed down the dip, indicating that the sand is progressively younger downdip. In the near-shore phases a regressive marker present in the regressive sand will occur in the sandy shales, shales, and muds below the sand, as it is traced downdip. For example, the Oligocene *Discorbis* at the base of the regressive *Discorbis* sand "climbs down" the section as seen in a regional dip section. This factor is of major importance in evaluating paleontological determinations for purposes of structural control.

The sands laid down in various advances and retreats of the Gulf Coast Tertiary seas are prolific sources of petroleum. In this paper the writers have described and discussed known concepts in view of their applicability to the interpretation of the depositional history of these sands. The concepts have been presented ideally without taking into consideration the influences effected by structural movements; but the application of these concepts is of considerable importance in a study of the Gulf Coast sediments. In several instances the Gulf Coast Tertiary stratigraphy illustrates text-book examples of the stratigraphic principles outlined, and so the application of these fundamental concepts has a direct bearing on the search for petroleum reserves.

[17] D. S. Malkin and D. A. Jung, *op. cit.*

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CORE ORIENTATION BY GRAPHICAL AND MATHEMATICAL METHODS[1]

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ABSTRACT

This paper reviews mathematical, graphical, and mechanical methods for correcting the apparent dips in oriented cores for the effect of the angle of deflection of the bore hole. In addition the common case is treated in which the core is not oriented but instead a regional or local strike is assumed. By means of examples, this solution and previously published solutions for the case of an oriented core are reduced to a step-by-step routine with convenient charts and formulas serving as double checks on each other. It is pointed out that in the case of an unoriented core, when the strike is assumed, there are usually two possible values for the true dip, one of which must be selected on the basis of geological probability.

INTRODUCTION

The problem of finding the true strike and dip from a core taken from a deflected well confronts nearly every petroleum geologist occasionally, and in most cases his convenient methods of solution are only approximate. One purpose of this paper is to present accurate methods which compete in convenience with approximate methods. Another purpose is to describe more than one method of solution so that the accuracy of the results may be checked and insidious errors of interpretation avoided.

Geologists, as a rule, have few occasions to use mathematics and with this in mind the following presentation has been simplified as much as possible.

The analogy between core-orientation problems and the well known problem of two tilts, first pointed out in this *Bulletin* in 1939,[3] permits the application to core-orientation problems of the methods of solution of the two-tilt problem. Early papers on the two-tilt problem[4,5,6,7] show a gradual progress toward the elimination of error and a simplification of methods.

[1] Read by title before the Association at Los Angeles, March 24, 1947. Manuscript received, September 30, 1947.

[2] Geologist, Continental Oil Company. The writer is greatly indebted to Curtis H. Johnson for aid and advice throughout the preparation of this paper, and for a critical examination of the manuscript. Martin Van Couvering generously furnished the mathematical solution in equation (7) and the use of the instrument illustrated in Figure 1. Thanks are due Roy M. Barnes, Los Angeles region geologist of the Continental Oil Company, for permission to publish this article.

[3] Curtis H. Johnson, "New Mathematical and 'Stereographic Net' Solutions to Problem of Two Tilts—with Applications to Core Orientation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 5 (May, 1939), pp. 663–85.

[4] A. Harker, "Graphical Methods in Field Geology," *Geological Magazine*, Vol. 1 (3) (1884), pp. 154–62.

[5] D. Jerome Fisher, "Some Dip Problems," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 3 (March, 1937), pp. 340–51.

[6] D. Jerome Fisher, "Problem of Two Tilts and the Stereographic Projection," *ibid.*, Vol. 22, No. 9 (September, 1938), pp. 1261–71.

[7] Edmund M. Spieker, "Problem of Two Tilts—Harker's Solution Corrected," *ibid.*, Vol. 22, No. 9 (September, 1938), pp. 1255–60.

Although there is undoubtedly much unpublished information specifically on the core-orientation problem in the files of the various consultants and well-service companies, very little has appeared in print.[8,9]

The writer has attempted to select from both the mathematical and graphical approaches the most direct and usable of the rigorous solutions, so that no range of angles need be excluded. The probable future development of tidelands by deflected drilling makes the high-angle applicability of these methods of increasing interest to the geologist and petroleum engineer.

Various companies and consultants have constructed instruments for duplicating the geometrical relationships existing in deflected wells. **Figure 1** shows

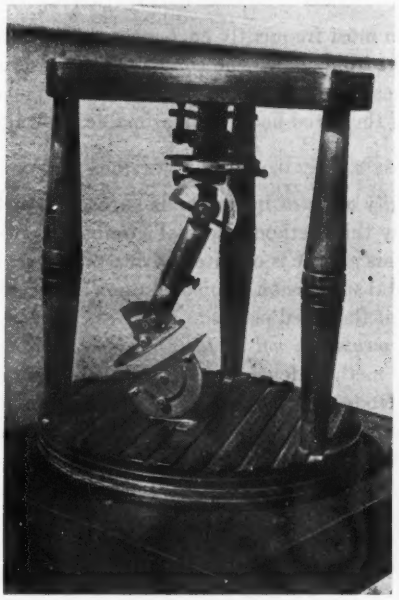

FIG. 1.—Instrument for solving core-orientation problems.

such an instrument designed and built in 1937 by Laurence I. Durgin, under the direction of Martin Van Couvering. A similar instrument was pictured by Lynton[10] in this *Bulletin* in the same year. These instruments are valuable when available, because they not only provide a rapid method of solution, but also en-

[8] Edward D. Lynton, "Laboratory Orientation of Well Cores by Their Magnetic Polarity," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 5 (May, 1937), pp. 580–615.

[9] Curtis H. Johnson, *op. cit.*

[10] Edward D. Lynton, *op. cit.*, pp. 612–13.

able the operator to visualize the problem in three dimensions, thereby eliminating errors of one or more quadrants. However, most of these instruments have a limited angular range. Furthermore, in cases in which there are two possible solutions, one solution may fall outside the range of the instrument.

TYPES OF PROBLEM

Core-orientation problems may be classified on the basis of what is known and what is unknown. Among the several combinations of known and unknown factors capable of solution, the following two general cases have been selected as being of widest interest.

CASE 1. NO CORE ORIENTATION

This is the problem most frequently encountered by geologists. The direction of the hole at the point from which the core is taken must be known as well as the apparent dip as measured on the core. In addition it must be possible to estimate the true strike of the cored bed with reasonable accuracy.

CASE 2. CORE ORIENTED BY VARIOUS METHODS

A. Core mechanically oriented by methods such as used by George A. Macready in California. By this method a special core barrel cuts a groove down the side of the core, and this groove is oriented with a photographic record of a compass needle in horizontal suspension, projected upon a film which is perpendicular to the axis of the hole at the cored point.

B. Apparent dips measured, not on the core, but on the walls of the bore hole, as by the "Dipmeter" method developed by Schlumberger Well Surveying Corporation.[11] Three electrodes spaced 120° apart around the periphery of the hole indicate the formational change on a bedding plane at three points, thus fixing the attitude of the bedding plane with respect to the hole. The electrodes are oriented with magnetic north by a photographic record of a compass needle in horizontal suspension, projected upon a film which is perpendicular to the axis of the hole.

It may be noted that in any method which photographs a compass needle in a horizontal plane upon a film not in a horizontal plane a small error of direction is introduced upon the film. For purposes of core orientation these errors may be ignored for hole deflections of less than 30°, and most of the pendulous systems in use do not record more than 20°. In the example used in this paper, with hole deflection of 50°, the error in direction would amount to 13°, while for a hole deflection of 30° the error would be only 3°.

Methods which photograph a compass card instead of a needle eliminate this error because the reading is made in one of the two directions of no distortion either in the vertical plane of the axis of tilt or in the plane of the direction of the

[11] H. G Doll, "The S.P. Dipmeter," *A.I.M.E. Petroleum Technology* (January, 1943), *Tech. Pub. 1547.*

hole. The Eastman method in which the compass card is photographed can be used for all angles of deflection between 12° and 90°.

C. Core oriented by a method of measuring magnetic polarity, as employed by the Sperry Sun Company. This method was originated in 1927 by H. N. Herrick of the Standard Oil Company of California, and further developed by Lynton[12] and associates, and measures the natural magnetic polarity of the core in the plane of the top of the core. If the hole is deflected it is necessary to make a preliminary correction by rotating the observed direction of magnetic north into the plane of the top of the core before making the correction for deflection of hole.

All three of the methods of orientation classified as Case 2 furnish the direction as well as the amount, of the measured dip in the core. It is then necessary to find the true direction and amount of dip.

GENERAL THEORY

The basic concept is that the well and core are imagined in a vertical position when the observed dip in the core is measured. Then the well is tilted into its true position and the resulting true dip and direction of dip are determined. The following quantities may be defined with respect to Figures 2 to 6, where sym-

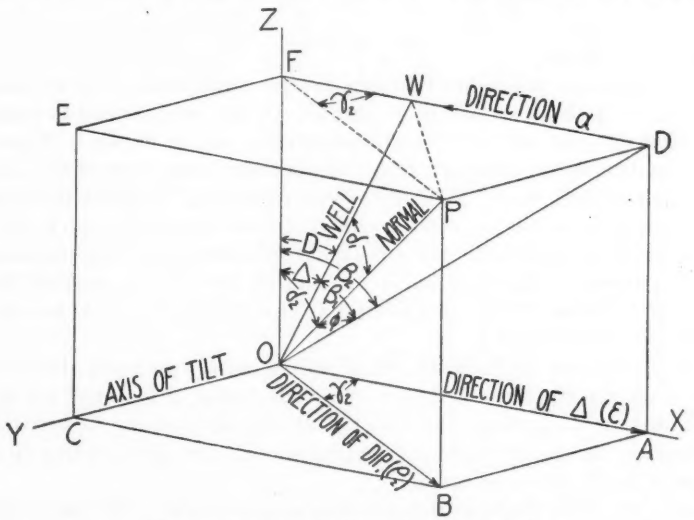

FIG. 2.—Geometrical relations in deflected well.

bols relating to the first position have the subscript 1, while those relating to the second, or tilted position, have the subscript 2. *OP* is the normal to the bedding plane, and *OW* is the deflected well in its true position at the cored point.

[12] Edward D. Lynton, *op. cit.*

α Direction of well
D Deflection of well (measured from vertical).
Δ Tilt of top of core (measured from horizontal. Equal to D, but opposite in direction. Top of core assumed perpendicular to axis of core)
ϵ Direction of Δ. This line is the reference line, and a vertical plane through it is perpendicular to the axis of tilt
δ_1 Observed dip in core
ρ_1 Direction of observed dip (as seen in top of core)
δ_2 True dip
ρ_2 Direction of true dip
γ_1 Difference between ϵ and ρ_1 (measured in plane of top of core)
γ_2 Difference between ϵ and ρ_2 (measured in the same direction as γ_1)
ϕ Component of γ in plane of bedding normal and axis of tilt
β Component of δ in plane normal to axis of tilt

Equations expressing the relations between these quantities are as follows.[13]

(1) $\text{Cos } \delta = \text{Cos } \beta \text{ cos } \phi$
(2) $\text{Sin } \phi = \text{Sin } \gamma \text{ sin } \delta$
(3) $\text{Tan } \beta = \text{Tan } \delta \text{ cos } \gamma$
(4) $\text{Tan } \phi = \text{Tan } \gamma \text{ sin } \beta$
(5) $\phi_2 = \phi_1$
(6) $\beta_2 = \beta_1 + \Delta$

These equations may be used directly to solve orientation problems classified in Case 2, as will be shown later by an example. Or they may be used to define the coordinates on polar and meridional stereographic nets as shown in Figure 3,[14] which may be used to solve such problems somewhat more conveniently. A simple example of such use of these nets is shown in Figure 7, where the point P_1 corresponds with the values of the apparent dip and direction of dip in the core in its assumed vertical position, and the point P_2 corresponds with the values of the true strike and dip after the well is rotated into its true position by the amount of Δ. Values of the other unknowns of equations (1) to (6) are also defined by the points P_1 and P_2.

Case 2 problems may also be solved by descriptive geometry, but a much more convenient graphical method is by an adaptation of Fisher's[15] use of bedding normals on the stereographic net (Fig. 8). This method may be preferred by some because the net is oriented with respect to north and gives the true direction of dip as it would appear on a map.

Case 1 problems are more difficult than those in Case 2, because of lack of information. They may be solved mathematically by means of the following equation which was derived by C. L. Clark for Martin Van Couvering in 1937,

[13] Curtis H. Johnson, *op. cit.*, pp. 665–67.

[14] Curtis H. Johnson, *op. cit.*, pp. 675–77.

[15] D. Jerome Fisher, "Problem of Two Tilts and the Stereographic Projection," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 9 (September, 1938), p. 1265.

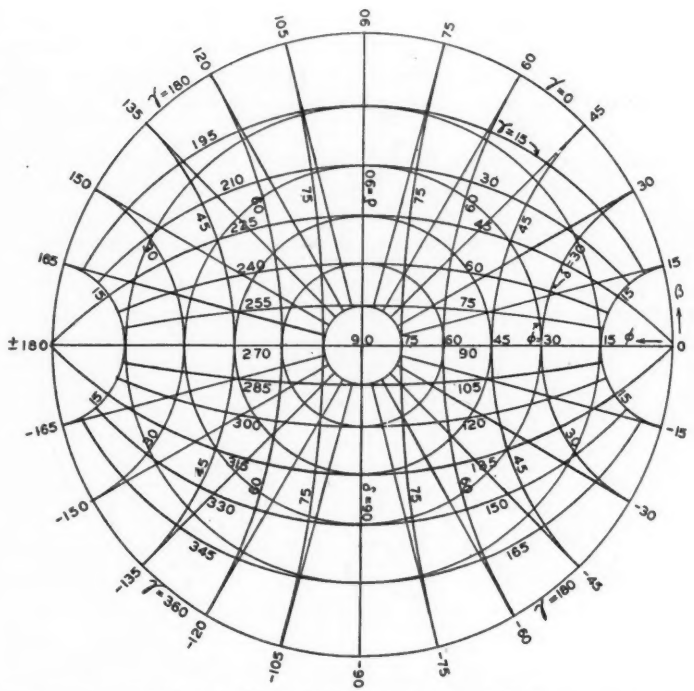

FIG. 3.—Stereographic net with ϕ as latitude and β as longitude in polar net and δ as latitude and γ as longitude in meridional net. (After C. H. Johnson.)

from the relationships illustrated in Figure 2. This solution has never before been published.

$$(7)\quad \operatorname{Tan}\delta_2 = \frac{\sin\Delta\cos\Delta\cos\gamma_2 \mp \cos\delta_1\sqrt{\sin^2\delta_1 - \sin^2\Delta\sin^2\gamma_2}}{\cos^2\delta_1 - \sin^2\Delta\cos^2\gamma_2}$$

After the amount of true dip (δ_2) is determined, other unknowns may be found from equations (1) to (6) if desired.

A graphical method of solving Case 1 problems was recently evolved by Curtis H. Johnson, using a stereographic net as shown in Figure 3. Actual use of the net is illustrated by an example to follow. By this method all the unknowns of equations (1) to (6) may be read from the net in their proper quadrants.

SOLUTION OF CORE-ORIENTATION PROBLEMS

To illustrate the actual steps involved in the various methods of solution, a single example is carried through all the methods described.

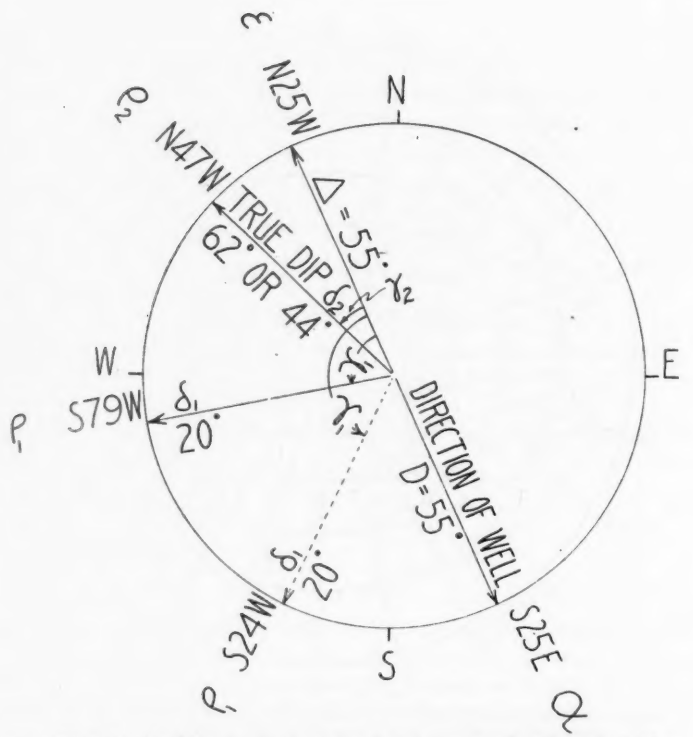

FIG. 4.—Plan showing determined values of various factors involved in type problem. Quantities bearing subscript 1 are measured while core is assumed vertical.

CASE 1. NO CORE ORIENTATION

Known:

a. Direction of well at cored point α = S. 25° E. Therefore ϵ = N. 25° W.

b. Amount of well deflection at cored point $D = 55°$. Therefore $\Delta = 55°$

c. Observed dip in core $\delta_1 = 20°$

d. Regional or local direction of dip assumed from other data in the vicinity ρ_2 = N. 47° W.

It follows that γ_2, the counterclockwise angle between the known direction of tilt of the top of the core (ϵ), and the assumed direction of true dip (ρ_2), is 22°.

Unknown:

e. Amount of true dip (δ_2)

f. Direction of observed dip in the core (ρ_1)

ρ_1 is not usually required by the geologist, but it is one of the known factors in Case 2 problems and it is an aid in visualizing the relationships existing.

By equation (7) the value of δ_2 is found to be either 62°05′ or 43°50′. Assume

that 62°05′ is selected on the basis of geological probability. If the direction of the observed dip (ρ_1) is desired it can be found by means of equations (2) and (5), from which ϕ is found to be 19°20′ and $\gamma_1 = 75°24'$. γ_1 is therefore S79°36′ W.

Similarly, if δ_2 is taken as 43°50′, ϕ is 15°02′; γ_1 becomes 130°40′ and ρ_1 is S.24°20′ W.

At this point it should be noted that there is a possibility of error in determining the proper quadrant for γ_1, and possibly other unknowns, when the mathematical solution is used. For the geologist whose skill in mathematics may have diminished it is recommended that the problem be solved by the use of the stereo-

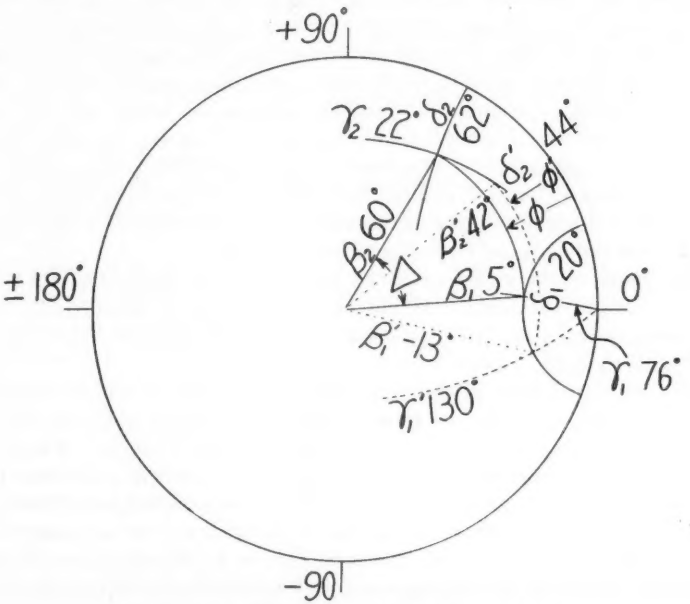

FIG. 5.—Use of stereographic net for Case 1 problems.

graphic net as in Figures 3 and 5, and the mathematical method used as a check if desired. This graphical method will show at once the proper quadrant for all unknowns, and in addition is much quicker than the mathematical solution.

Preparation of stereographic net.—Paste a meridional stereographic net on a sheet of aluminum, plywood, or heavy cardboard. Place a short pin such as a thumb tack, at the center.

From the polar stereographic net make a tracing of the concentric circles only, on the smooth side of tracing cloth. One radius may also be drawn and marked 0°. Turn the tracing cloth over when in use and mark on the dull side.

GRAPHICAL METHOD FOR CASE 1 PROBLEMS

Turn the meridional stereographic net so that one pole is at the right side, as in Figures 3 and 5. The amount of dip (δ) is represented by the latitude lines of the meridional net and increases from 0° at the right-hand pole to 90° at the equator. The dip direction (γ) is represented by the meridians and increases from 0° at the top (first quadrant) to 180° at the bottom (fourth quadrant).

Place a sheet of tracing paper on the center pin and sketch the latitude line corresponding with $\delta_1 = 20°$, and the meridian corresponding with $\gamma_2 = 22°$, then place a white sheet of paper under the tracing to hide the superfluous lines of the meridional net. Place the tracing of the concentric circles on the pin over the tracing paper. Draw a radius 55° from the 0° radius, the 55° (Δ) being conveniently measured along the edge of the net. Rotate this tracing over the tracing paper on which were sketched the δ_1 latitude and γ_2 meridian, until a position is found where one of the 55° circular arcs included between the drawn radii will just exactly reach from the δ_1 latitude to the γ_2 meridian. The arc thus found fixes the values of all the unknowns of equations (1) to (6). Reading to the nearest degree, ϕ has the value 19°, $\beta_1 = 5°$ and $\beta_2 = 60°$. Remove the masking white paper and read on the latitude lines of the meridional net the value of δ_2 (62°) where the counterclockwise radius β_2 (60°) cuts the γ_2 (22°) meridian.

The manipulations here described result from the equations (1) to (6) and may be checked backward from the answer by means of those equations if the additional quantity, γ_1 (76°) is picked off the meridional net where the radius β_1 (5°) cuts the δ_1 (20°) line of latitude.

In Case 1 problems, as previously noted, two answers are usually possible. In the foregoing example, the alternate solution is shown in Figure 5 as dotted lines, where $\phi' = 15°$, $\beta'_1 = -13°$, $\beta'_2 = 42°$, $\delta'_2 = 44°$ and $\gamma'_1 = 130°$. A study of the figure will show why this double solution occurs and will also show that for certain values of Δ, γ_2, and δ_1, there may exist only one answer or no answer.

In actual practice other information in the area will be necessary to decide which of the two values of true dip (δ_2) is correct. In the case where no answer is possible it is obvious the assumption of the true direction of dip was in error, if no error can be ascribed to the hole deviation or the amount of dip observed in the core.

CASE 2. CORE ORIENTED BY VARIOUS METHODS

A. Core mechanically oriented

B. Core oriented by "dipmeter" method

Known:

a. Direction of well at cored point α = S. 25° E. ϵ = N. 25° W.

b. Amount of well deflection at cored point $D = 55°$ $\Delta = 55°$

c. Observed dip in core $\delta_1 = 20°$

d. Direction of observed dip ρ_1 = S. 79° W. Therefore $\gamma_1 = 76°$

Unknown:

e. Amount of true dip (δ_2)

f. Direction of true dip (ρ_2)

MATHEMATICAL METHOD FOR CASE 2 PROBLEMS

The known factors above are sufficient to allow the use of equations (1) to (6) for the mathematical solution. By this means the following values are found in the order named:

$$\beta_1 = 5°15'$$
$$\phi = 19°20'$$
$$\beta_2 = 60°15'$$
$$\gamma_2 = 22°00'$$
$$\delta_2 = 62°05'$$

For convenience a nomogram (Fig. 6) was prepared which may be read to the nearest degree, and which is believed to be as accurate as the original data warrant. Values for the foregoing symbols may be found by the following steps.

1. Find β_1
   Tan β_1 = Tan δ_1 cos γ_1
   Set straight edge on a scale A at 20° (δ_1) and on scale D at 76° (γ_1)
   On scale B read 5° (β_1)
2. Find ϕ
   Tan ϕ = Tan γ_1 sin β_1
   Set straight edge on scale A at 76° and on scale C at 5°
   On scale B read 19° (ϕ)
3. Find β_2
   55° + 5° = 60°
4. Find γ_2
   Tan γ_2 = Tan ϕ/Sin β_2
   Set straight edge on scale B at 19° and on scale C at 60°
   On scale A read 22°, (γ_2)
5. Find δ_2
   Tan δ_2 = Tan β_2/Cos γ_2
   Set straight edge on scale B at 60° and on scale D at 22°
   On scale A read 62° (δ_2)

GRAPHICAL METHODS FOR CASE 2 PROBLEMS

Method of simple rotation by amount of hole deviation.—Turn the stereographic net as illustrated in Figs. 3 and 7. Place a piece of tracing paper on the center pin and mark 0° point. Locate intersection of P_1 (20°) latitude and γ_1 (76°) meridian and mark this P_1. Rotate the tracing paper counterclockwise the amount of Δ (55°). P_1 is now at the location of P_2 and values of the true dip δ_2 (62°), and γ_2 (22°) may be read on the underlying stereographic net. Since γ_2 is the counterclockwise angle from ϵ to ρ_2, the direction of true dip is N. 47° W. Values of the other unknowns may be read at points P_1 and P_2 if desired.

Method of normals to bedding and top of core.—Turn the meridional stereographic net so that one pole is up, as in Figure 8. Place a sheet of tracing paper on

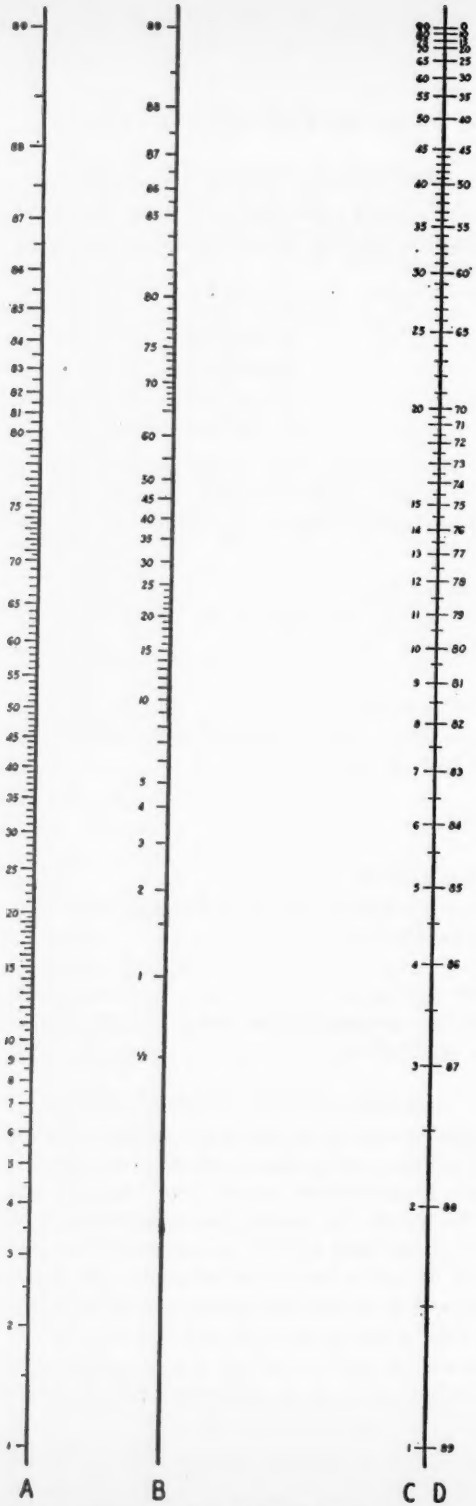

FIG. 6.—Nomogram for use with equations (1) to (4).

the pin and mark the location of N., S., E., and W. Draw a line from the center in the direction of observed dip, S. 79° W. Turn this line to *W* and measure out from center $\delta_1 = 20°$. This point represents the normal to the bedding plane. Rotate the paper back to its original position and draw a line from center in the direction of Δ, N. 25° W. Rotate this line to the *W* position and mark a point $\Delta = 55°$ from center. This represents the normal to the top of the core located

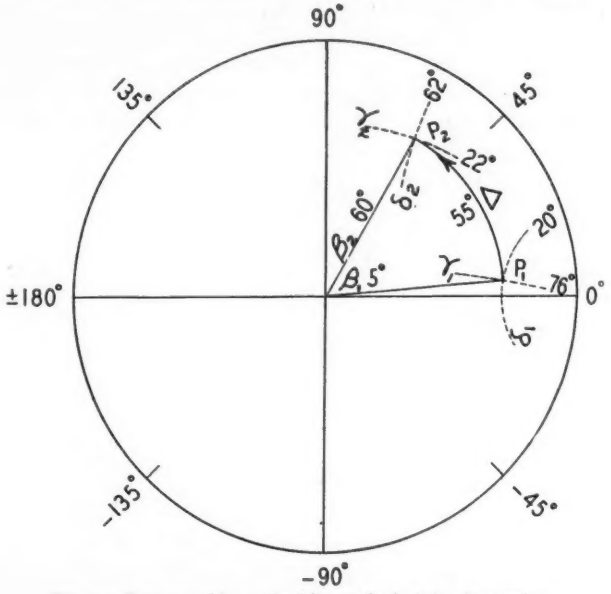

FIG. 7.—Case 2 problem solved by method of simple rotation.

in its tilted position in the well. With the tracing paper in the same position move δ_1 along a latitude line for 55° and mark the point δ_2. Draw line from center through δ_2. Rotate tracing paper back to the *N* position and read direction (ρ_2) of true dip (N. 47° W.) on edge of net. Rotate δ_2 to *N* position and read amount of true dip (62°) from center.[16] As a matter of interest it may be noted that in this method β is measured by the meridians from the zero meridian which passes through the center of the meridional net, and ϕ is measured on the meridional net by the latitude lines from the equator as zero. In effect, the values of δ are measured by the latitude lines and γ by the meridians of an imaginary polar stereographic net.

Thus, with Δ normal lying on the equator in the direction *W*, δ_1 defines β_1 as 5° and ϕ as 19°. On the circumference of the net the values of γ_1 (76°) and γ_2 (22°) may be read.

[16] For a discussion of this method as used in the two-tilt problem see D. Jerome Fisher, *op. cit.*

C. Core oriented by magnetic polarity.—This method, described by Lynton,[17] is based on the premise that the particles in the core are magnetized in the direction of the earth's magnetic field at the cored point. The core is held in a horizontal position and rotated beneath a system of opposed magnets, while shielded from outside interference. The instrument is extremely sensitive and registers the direction of greatest magnetic intensity which is marked on the side and

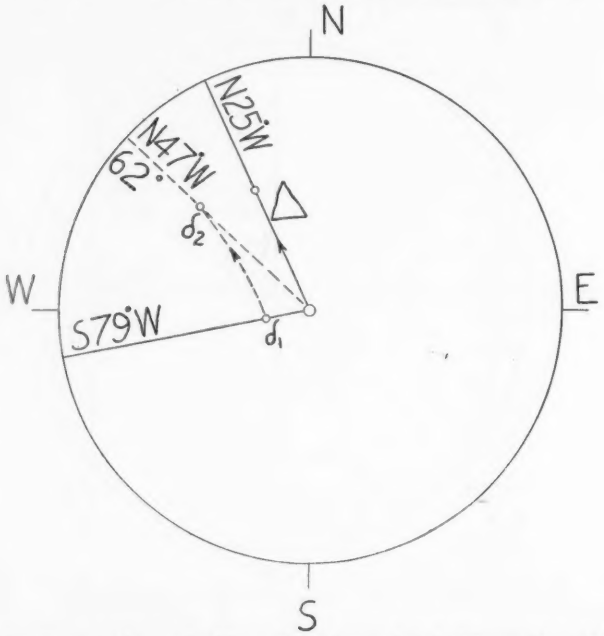

FIG. 8.—Case 2 problem solved by method of normals to bedding and top of core.

across the top of the core. Since this direction is measured in the plane of the top of the core it will not be the true direction in the horizontal plane if the well deviates from the vertical at the cored point.

Before the methods of correcting for hole deviation are applied it is therefore necessary to make a preliminary correction to locate the reference line (ϵ) on the top of the core.

The correction may be made by the use of descriptive geometry or other graphical or mathematical methods, but in order to use the methods previously discussed in this paper the following analogies may be employed.

The direction of a vector representing the total earth's magnetic field at the cored point may be considered the normal *OP* in Figure 2. This direction may be determined by dip compass or from published tables.

[17] Edward D. Lynton, *op. cit.*

Next consider the magnetic potential plane, perpendicular to OP, and analogous to a bedding plane. The dip of this plane, analogous to the true dip of a bedding plane (δ_2), is opposite to that of OP, or 90° minus the dip of the magnetic field vector, in the direction ρ_2. Since ϵ, the direction of tilt of the top of the core in the horizontal plane, is known from the well survey, γ_2 is known.

For cores taken in the northern hemisphere the direction of *magnetic south*, as determined by Lynton's magnetic method, is the apparent direction of dip of the magnetic potential plane in the plane of the top of the core, analogous to the direction of apparent dip, ρ_1, in Figure 4.

The apparent dip of the magnetic potential plane corresponds with the apparent dip measured in a core (δ_1), but is not determined in the magnetic problem.

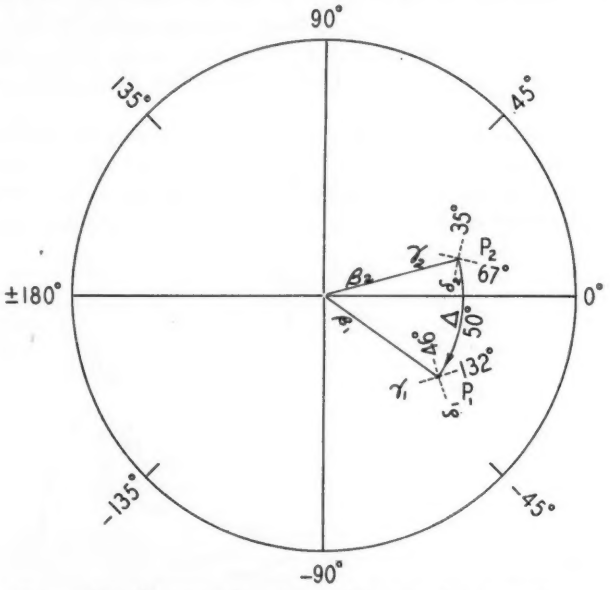

FIG. 9.—Use of stereographic net for making correction of direction of magnetic field in deflected well.

In order to locate the trace of ϵ in the plane of the top of the core it is necessary to find γ_1. From the foregoing analogies it is seen that the following quantities are known: Δ, δ_2, ρ_2, ϵ (in horizontal plane), and γ_2.

To solve for γ_1 any of the solutions heretofore presented for Case 2 problems may be used except that the knowns and unknowns are now interchanged. The method of simple rotation of the stereographic net is recommended and results may be checked by other methods if desired.

The following example may make this clear.

Known: (by analogy with Figures 2 and 4) $\Delta = 50°$. ρ_2 = S. 16° W. (direction of dip of magnetic potential plane). ρ_1 (direction of magnetic south in top of core. ϵ = S. 83° W. (direction of Δ). $\gamma_2 = 67°$. Dip of magnetic vector (OP) 55°. $\delta_2 = 35°$ (dip of magnetic potential plane). It is desired to locate the trace of the direction ϵ on the core top.

Using the meridional stereographic net as in Figure 3, place a sheet of tracing paper on the pin and mark the 0° point at right side. Locate the point P_2 at the intersection of the γ_2 meridian (67°) and the δ_2 latitude (35°). It may be noted that ϕ is 31°30′. Rotate the tracing paper *clockwise* the amount of Δ (50°). P_2 is now at the location of P_1 and here the value of γ_1 is read as 132°30′ and δ_1 as 45°40′ (Fig. 9).

As a check equations (1) to (6) may be used to obtain the following results: $\phi = 31°50'$, $\delta_1 = 45°39'$ and $\gamma_1 = 132°25'$. Since γ_1 is the angle between ϵ and ρ_1, measured in the plane of the top of the core, ϵ may be marked on the core by measuring *counter-clockwise* 132°25′ from the direction of magnetic south (ρ_1) marked on the top of the core.

Having located the reference direction (ϵ) on the core top, the usual procedure in Case 2 problems is applied to correct for deflection of the well. In the foregoing example we may assume the following known quantities: $\Delta = 50°$, ϵ = S.83° W., $\delta_1 = 30°$ (dip measured on the core), $\gamma_1 = 131°$ (measured on core top).

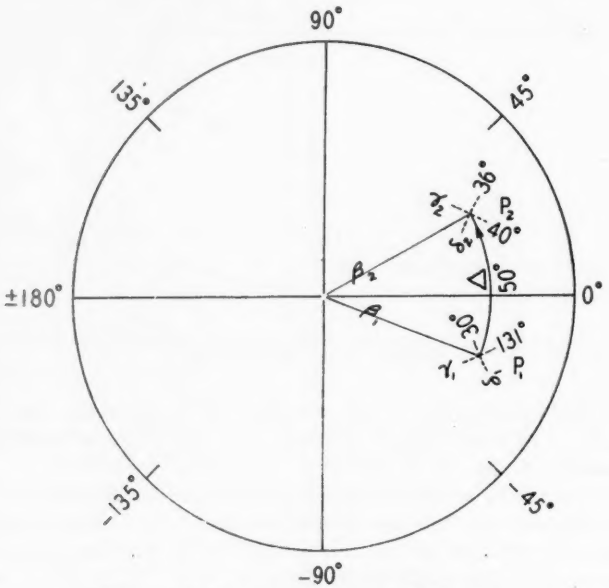

FIG. 10.—Final correction of example in Figure 9.

Locating P_1 on the stereographic net and rotating counterclockwise 50° to the position of P_2, the following quantities may be read: $\delta_2 = 36°$, $\gamma_2 = 40°$, $\phi = 22°$. Checking by means of equations (1) to (6) the results are: $\phi = 22°10'$, $\beta_1 = -20°44'$, $\beta_2 = 29°16'$, $\delta_2 = 36°06'$, $\gamma_2 = 39°48'$. Thus, the true dip (δ_2) is 36° and since its direction (ρ_2) is equal to γ_2 plus ϵ (measuring counter-clockwise), the direction of true dip is S. 43° W.

CONCLUSIONS

Experience indicates that for general use the graphical methods, utilizing the stereographic net, are by far the quickest and surest for all types of core-orientation problems. The average operator often will desire to check his results mathematically but it is safe to say that he will discover that errors are more likely to occur in the mathematical work than in the graphic solution.

When much depends on correct direction and amount of dip, as may well be the case in offshore deflected drilling, it may be found advisable to take oriented cores by two methods and check the corrections by more than one of the methods described herein.

DISCUSSION

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In preparing this article Hugh McClellan has made a real contribution to the literature of core orientation and the determination of subsurface strike and dip. It was my pleasure to be consulted on some of the mathematical aspects of the paper, and from these contacts I acquired a great admiration for his tenacity in gaining a thorough understanding of the problem and in reducing it to geological terminology. One of the real chores he accomplished was the re-derivation of the Clark-Van Couvering equation using the basic figure and nomenclature of my 1939 paper.†

DETERMINATION OF QUADRANTS

In his paper Hugh McClellan recommends the solutions by stereographic nets as removing the uncertainty of quadrant of the answer as calculated by the various equations. I agree that this is one of the good arguments in favor of graphical methods, but for those who would like to check their stereographic net solutions mathematically, it is suggested that the following tables will be found convenient:

McClellan's Case 2 problems.—First, remember always to measure from the direction of dip of the top of the core to the apparent direction of dip of the beds in the core clockwise or counter-clockwise, whichever yields a value of γ_1 less than 180° (remembering, also, to measure γ_2 in the same direction). Second, remember that in geological terminology the apparent dip, δ_1, is between zero and 90°. Then:

Given		*Calculated*	
δ_1	γ_1	ϕ	β_1
1st quadrant	1st quadrant	1st quadrant	1st quadrant
	2d quadrant		4th quadrant

* General Petroleum Corporation.
† Curtis H. Johnson, *op. cit.*

After determining β_1 we add Δ, the amount of dip of the top of the core. Unless the well has been deflected so severely as to be actually drilling *up*, Δ will be between zero and 90°. Whatever its value, however, it is simply added to β_1, and hence there can be no ambiguity about the quadrant in which $\beta_2 = \beta_1 + \Delta$ will fall. In the commonest cases β_2 will be in the first or fourth quadrant; $\phi_1 = \phi_2$ will be in the first quadrant; and the following relations will hold:

Given		*Calculated*	
ϕ	β_2	δ_2	γ_2
1st quadrant	1st quadrant	1st quadrant	1st quadrant
	4th quadrant		2d quadrant

In the relatively rare cases where β_2 is in the second or third quadrant (the third quadrant would be *very* rare!) the following relations hold (where γ_2 and δ_2 refer to the strike and dip on the *underside* of the bed):

Given		*Calculated*	
ϕ	β_2	δ_2	γ_2
1st quadrant	2d quadrant	1st quadrant	3d quadrant
	3d quadrant		4th quadrant

Similarly, in the *preliminary* calculation in *magnetic* core-orientation problems (see the *corrected* analogy to the two-tilt problem described at the end of this discussion):

Given		*Calculated*	
δ_2	γ_2	ϕ	β_2
1st quadrant	1st quadrant	1st quadrant	1st quadrant
	2d quadrant		4th quadrant

$$\beta_1 = \beta_2 - \Delta$$

In common cases β_1 = first or fourth quadrant, then:

Given		*Calculated*	
ϕ	β_1	δ_1	γ_1
1st quadrant	1st quadrant	1st quadrant	1st quadrant
	4th quadrant		2d quadrant

In relatively rare cases β_1 = third or second quadrant (second quadrant *very* rare!). Then:

Given		*Calculated*	
ϕ	β_1	δ_1	γ_1
1st quadrant	3d quadrant	1st quadrant	4th quadrant
	2d quadrant		3d quadrant

McClellan's Case 1 problems.—The only equation presented for solving these problems mathematically is the Clark-Van Couvering equation. The value of δ_2 obtained through the use of this equation is always in the first quadrant if by definition we limit a dip to less than 90°. However, the beds may sometimes be overturned as a result of the correction for hole deflection, in which case δ_2 is still less than 90°, but is measured on the opposite side of the bed. The most confusing thing about this equation is that it yields a single solution, a double solution or no solution at all, depending on the magnitudes of δ_1, γ_2 and Δ introduced as data into the equation. As a specific example the following table has been compiled for a particular value of the observed dip in the core (giving δ_1) and a particular assumed true strike (giving γ_2) for various values of hole deflection, Δ.

Let $\delta_1 = 45°$ and $\gamma_2 = 60°$ ($= 240°$ if overturned)

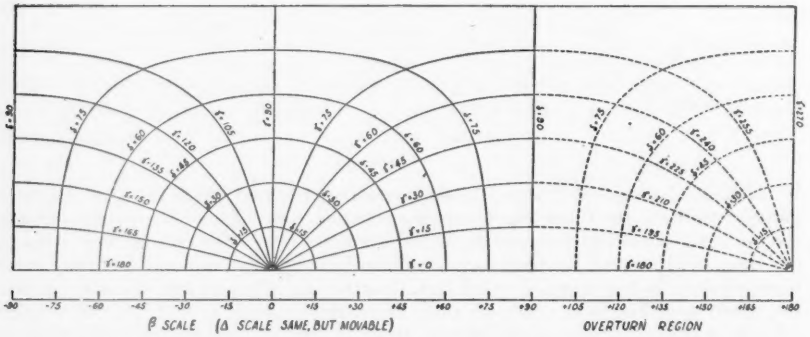
Range of Δ	*Nature of Solution*	*Quadrants of Answers*	
		γ_1	δ_2
0° −35°	Single	First	First
35° −45°	Single	Second	Both first
45°−55½°	Double	Both second	Both first
55½°−124½°	None	....	....
124½°−135°	Double	(Overturn) Both first	(Overturn) Both first
135° −144½°	Single	(Overturn) First	(Overturn) First
144½°−225°	Single	(Overturn) Second	(Overturn) First

With all these complexities, it is perhaps better to use the graphical solution with the aid of the stereographic net as described by McClellan or the equivalent net described in the following paragraphs.

ANOTHER USEFUL NET

The stereographic net solution for McClellan's Case 1 problems requires intersecting the δ_1 and γ_2 curves respectively with two radii enclosing an angle of Δ in such a way that the two intersections occur on a common polar circle, or curve of constant ϕ. Perhaps the following new method may appeal to some geologists who would rather work in rectangular coordinates than in polar coordinates. In the accompanying figure the horizontal axis is the β axis and the vertical axis (not used in the computations) is the ϕ axis. The slightly squared circles about $\beta = 0°$ and $\beta = +180°$ are lines of equal δ while the curves radiating from $\beta = 0°$ and $\beta = +180°$ are lines of equal γ.

To solve McClellan's Case 1 problems with the aid of this net, simply mark the



amount of hole deflection, Δ, on the edge of a ruler. Then, ***keeping this marked ruler parallel to the β axis***, run the left-hand mark along the δ_1 curve until the right-hand mark lies on the γ_2 curve. With the ruler in this position read δ_2 at the right-hand mark (and, if desired, γ_1 at the left-hand mark). Then continue to move the left-hand mark along the δ_1 curve to see if there may be a second position of the ruler at which the right-hand mark will again lie on the γ_2 curve. If so, this is the second solution described by McClellan. Perhaps *no* position of the ruler parallel with the β axis will be found where the left-hand mark will lie on the δ_1 curve while the right-hand mark lies on the γ_2 curve. This indicates no solution is possible, and suggests an error in measuring the apparent dip in the core, an improper assumption of regional strike or an error in the direction and/or amount of the hole deflection.

In cases of large hole deflection, or large dips and moderate hole deflection, overturn of the beds in the core may occur as described in my 1939 paper and as shown in the preceding table for values of Δ over $124\frac{1}{2}^\circ$. These cases may be solved with the aid of the rectangular coordinate net accompanying this discussion if the right-hand mark on the ruler lies on the *prolongation* of the γ_2 curve, marked as 180° plus γ_2. All such overturned solutions by this method will yield δ_2 (less than 90°) the dip on the *opposite* side of the bed from that on which the apparent dip in the core was measured, in the region of the net where the curves are shown as dotted lines.

In the rectangular coordinate net method described here, the marked ruler may be kept parallel to the β axis by means of a pair of triangles, a parallel ruler, or the horizontal arm of a draughting machine. Before leaving the discussion of this net it should be noted that all problems of two-tilts and core orientation may be solved with its aid and, if the computer has a draughting machine available, this net may be decidedly more convenient than the stereographic nets heretofore described and recommended for all such problems. The fundamental unit of this rectangular coordinate net, developed by the writer for another purpose, is shown to 1° intervals in: S. M. Rock, "Three Dimensional Reflection Control," *Geophysics*, Vol. 3, No. 4 (October, 1938) pp. 340–48.

A NEW PROBLEM

McClellan has treated several problems he has found from experience to be commonly encountered in geological work. I would like to suggest an interesting variation which may or may not have practical importance, but which shows how flexible a tool the described methods may become as the geologist becomes more familiar with their use.

There is a method of core orientation offered by the Eastman Oil Well Surveying Company under the name of "Corex." In this method the well is presumed to have been

surveyed for both amount and direction of deflection, where a core was taken, or just above a core which is about to be taken and oriented by the "Corex" method. In taking the core a groove is made along one side of the core, and before the core is broken off a photograph is taken in the hole showing the position of the low side of the top of the core, the position of the groove and, incidentally, the amount of the hole deflection up to about 7°.

As ordinarily employed by "Corex," this is simply McClellan's Case 2 problem, the measured strike and dip in the core being γ_1 and δ_1 (remembering that γ_1, by definition, is measured with respect to the low side of the top of the core), the amount and direction of hole deflection being Δ and α, and the calculation yielding γ_2, δ_2, hence the true strike and dip. In lieu of calculations of the true strike and dip, the Corex service provides an orienting device, or "Reader," similar to that pictured in McClellan's Figure 1. However, in the interesting variation now proposed, suppose that for some reason the independent directional hole survey was not made, was lost or was considered untrustworthy. If the hole deflection were not over seven degrees and if, as in McClellan's Case 1 problem, the true regional strike could be confidently assumed, the problem could be solved as follows.

By measuring the apparent strike (referred to the low side of the top of the core) and dip in the core, γ_1, and δ_1 are known as in the usual "Corex" procedure. The *amount* of hole deflection, Δ, is known from the "Corex" photograph (if not over seven degrees), hence γ_2 and δ_2 can be calculated by any of the recognized methods. Now, δ_2 is, of course, the true amount of dip, determined accurately without introducing any assumptions even though the *direction* of hole deflection is not known. Moreover, γ_2 is the angle in the horizontal plane measured from the direction opposite to the direction of hole deflection to the true direction of dip. If the true direction of dip can be confidently assumed (as in McClellan's Case 1 problem), *the direction of hole deflection can be calculated* by adding or subtracting γ_2 from the true direction of dip.

CORRECTIONS

The publication of McClellan's paper now makes it imperative for me to correct an error in my paper in this *Bulletin* for May, 1939. The error was first pointed out to me by E. Ray Webb of the Sperry-Sun Well Surveying Company a few months after the paper was published, and I must apologize to Webb and to the editor and readers of this *Bulletin* for postponing the correction until this late date. I did, however, point out the error to McClellan when he first began to prepare his paper for presentation to the Pacific Section of the A.A.P.G. and for subsequent publication in this *Bulletin*.

When working with cores oriented by means of their magnetic polarity, the magnetic north side of the core is first determined. From the known amount and direction of deflection of the well and from the direction and "dip" of the earth's magnetic field measured at the well site, the angle in the top of the core between the magnetic north side of the core and the direction of dip of the top of the core must be calculated and marked on the core (tabulate 4, page 679 of my 1939 paper).

On page 680 of that paper the analogy between this problem and the problem of two-tilts was given incorrectly by considering the direction and "dip" of the earth's magnetic field as analogous to the present direction and amount of dip of the beds below an unconformity in the two-tilt problem. Actually the earth's magnetic field is analogous to the *normal* to these beds. Thus, if by "Magnetic potential surface" we mean the plane normal to the earth's magnetic field, tabulates (a) through (e) on page 680 of my paper should be corrected to read:

Let (a) The amount of dip of the top of the core $=\Delta$ (corresponding with the present amount of dip of the beds above an unconformity)

(b) The true amount of dip of the magnetic potential surface $=\delta_2$ (corresponding with the present amount of dip of the beds below an unconformity)—

(i.e. the "dip" of the earth's magnetic field below the horizontal at the well site $= 90° - \delta_2$)

(c) The true direction of dip of the magnetic potential surface referred to the direction of dip of the top of the core $= \gamma_2$ (corresponding with the present direction of dip of the beds below an unconformity referred to the direction of dip of those above)—(i.e., γ_2 = the angle between true magnetic *south* at the well site and the direction of dip of the top of the core)

Then (d) The apparent amount of dip of the magnetic potential surface referred to the top of the core as horizontal $= \delta_1$ (corresponding with the original amount of dip of the beds below an unconformity)

(e) The apparent direction of dip of the magnetic potential surface referred to the top of the core as horizontal and to the direction of dip of the top of the core $= \gamma_1$ (corresponding with the original direction of dip of the beds below an unconformity referred to the direction of dip of those above)—(i.e., γ_1 = the angle between the magnetic *south* side of the core and the direction of dip of the top of the core as seen in the plane of the top of the core).

It may also be permissible in this discussion to correct another error in my paper—this one discovered by Hugh McClellan: In Fig. 2, page 666, "A" and "B" should be interchanged.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

RECENT PUBLICATIONS

BRAZIL

*"Histórico do Serviço Geológico e Mineralógico e Considerações sobre suas Atividades." "Índice dos Boletins 1–99" (History of the Geological and Mineralogical Survey and Notes on Its Activities. Index of Bulletins 1–99), by Gerson de Faria Alvim, Glycon de Pavia, and Jose Menescal Campos. *Serviço Geológico e Mineralógico do Brasil Bol. 100* (Rio de Janeiro, 1946). 223 pp. In Portuguese.

*"Sedimentos Mesozóicos na Baía de São Marcos, Estado do Maranhão" (Mesozoic Sediments on the Bay of Sao Marcos, Maranhao), by Llewellyn Ivor Price. *Brasil Div. Geol. e Min. No. 40* (Rio de Janeiro, June, 1947). 7 pp. text; 3 pls. (4 photographs and 1 map). In Portuguese; résumé in English.

*"Brazil Has Extensive Sedimentary Areas Favorable to Accumulation of Petroleum," by Avelino Ignacio de Oliveira. *Oil and Gas Jour.*, Vol. 46, No. 37 (Tulsa, January 15, 1948), pp. 48–50, 145; 3 photographs, 1 index map.

CHINA

*"On the Triassic Stratigraphy of Szechuan," by C. H. Chao. *Bull. Geol. Soc. China*, Vol. 24, Nos. 3–4, December, 1944 (Szechuan, May 1, 1946), pp. 147–62; 4 pls. (stratigraphic sections and maps). In English.

*"On the Facies of the Carboniferous of the Kunming Region, Eastern Yunnan, with Special Reference to the Bauxite Deposits," by Peter Misch. *Ibid.*, Vol. 26, Nos. 1–4 (Nanking, December, 1946), pp. 1–64; 2 pls., 20 figs.

*"On the Discovery of Upper Permian (Lopingian in Western Yunnan," *ibid.*, pp. 65–82; 3 figs.

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*"Oil Shale Exploration for Production of Oil," by W. H. Cadman. *Inst. Petrol. Review*, Vol. 1, No. 11 (London, November, 1947), pp. 365–72.

*"Photogeology Applied to Search for New Petroleum Reserves," by Laurence Brundall. *Petroleo Interamericano*, Vol. 6, No. 1 (Tulsa, Oklahoma, January, 1948), pp. 44–48; 4 photographs. In Spanish and English.

*"Use of Electric Logs in Locating Porous Zones," by H. N. Lyle. *Ibid.*, pp. 49–53; 2 figs.

*"Report of the Committee on Research on Petroleum, Society of Economic Geologists," by K. C. Heald. *Econ. Geol.*, Vol. 42, No. 7 (Urbana, Illinois, November, 1947), pp. 676–78.

**Bibliography and Index of Geology Exclusive of North America, Vol. 11, 1945–1946* (1947), by Marie Siegrist and Eleanor Tatge. 474 pp. Geological Society of America, 419 West 117th Street, New York 27, N. Y.

Reviews of Petroleum Technology, Vol. 7 (Covering 1941–1945), by F. H. Garner, E. B. Evans, and George Sell. 535 pp. Published by the Institute of Petroleum, 26 Portland

Place, London W. I. (1947). Clothbound. Approx. 6×9 inches. Price, 21s.

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*"Bibliographie des Sciences Géologiques," Deuxieme Serie, Tome 17 (1946), published by the Société Géologique de France with the cooperation of the Société Française Minéralogie. Bibliography of publications received in Paris in 1946. 525 pp. Soc. Geol. de France, 28, rue Serpente VI^e, Paris. Price, 500 fr.

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*"Abstracts of Papers Presented at Section E Meeting in Chicago, December 26–27, 1947." *Ibid.*, pp. 1271–80.

*"Index to Volume 58 (July–December). *Ibid.*, pp. 1281–94.

JAPAN

*"Mining for Oil in Japan," by Gerald B. Shea. *Producers Monthly*, Vol. 12, No. 2 (Bradford, Pennsylvania, December, 1947), pp. 19–28; 7 figs., 1 table, 1 photograph.

NORTH CAROLINA

*"Oligocene and Lower Miocene Microfossils from Onslow County, North Carolina," by James D. McLean, Jr. *Notulae Naturae*, No. 200 (Acad. Nat. Sci. Philadelphia, Pennsylvania, December 12, 1947). 9 pp.

OHIO

**Geologic Map of Holmes County, Ohio*, by George W. White. *Ohio Geol. Survey*, Columbus (1947). Single sheet, 16.5×31.5 inches, colored. Scale, 1.125 inches equals 1 mile. Price, $0.50 plus 2 cents tax in Ohio.

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PACIFIC REGION

*"Drilling on Bikini Atoll, Marshall Islands," by H. S. Ladd and J. I. Tracey. *Science*, Vol. 107, No. 2768 (Washington, D. C., January 16, 1948), pp. 51–55; 2 figs.

POLAND

*"Polish Oil Industry—Today's Position, Tomorrow's Prospects," by Hugo Burstin. *Oil and Gas Jour.*, Vol. 45, No. 35 (Tulsa, January 1, 1948), pp. 26–27, 119–20; 6 tables, 1 geological map.

RUSSIA

*"Memories of the Baku Oilfields in 1900," by A. Beeby Thompson. *Inst. Petrol. Review*, Vol. 1, No. 11 (London, November, 1947), pp. 345–53; 5 photographs.

UTAH

"Geology of the Whiterocks River-Ashley Creek Area, Uintah County, Utah," by Douglas M. Kinney and Joseph F. Rominger. *U. S. Geol. Survey Prelim. Map 82*, Oil and Gas Inves. Ser. (December, 1947). Single sheet, 39×40 inches. Scale, 1 inch equals 1 mile. For sale by Director, U. S. Geological Survey, Washington 25, D. C. Price, $0.60.

DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 21, No. 6 (November, 1947).

"Conodonts from the Type Section of the Sweetland Creek Shale in Iowa," by A. K. Miller and Walter Youngquist.

"Tertiary Non-marine Ostracoda from the Salt Lake Formation, Northern Utah," by Frederick M. Swain.

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"*Aulacopleura* and the Otarionidae," by Alois Přibyl.

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"Relations of the Invertebrate Paleontologist to Geology," by J. Marvin Weller.

* *Journal of Paleontology* (Tulsa, Oklahoma), Vol. 22, No. 1 (January, 1948).

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"Two Upper Cambrian *Elvinia* Zone Trilobite Genera," by James L. Wilson.

"Lower Ordovician Brachiopods from Junee District, Tasmania," by Ida A. Brown.

"Upper Devonian Compound Tetracorals from the Martin Limestone," by Erwin C. Stumm.

"Additions to the Devonian Conodont Faunas of Western New York," by Walter Youngquist, Raymond R. Hibbard, and Irving G. Reimann.

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"Some Additional Cephalopods from the Pennsylvanian of Ohio," by Myron T. Sturgeon and A. K. Miller.

"A Triassic Crinoid from Mexico," by Raymond E. Peck.

"Eocene Charophyta from North America," by Raymond E. Peck and Carl C. Reker.

"Eocene Echinoids from Panama," by C. Wythe Cooke.

"Halosauridae from the California Tertiary," by Lore R. David.

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"Diatomaceous Deposits at Lake Toba," by H. W. van der Marel.

"Suggestions to Contributors."

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EASTERN INTERIOR REGIONAL MEETING, ST. LOUIS, JANUARY 14–15

The Eastern Interior regional meeting, sponsored by the Illinois Geological Society and the Indiana-Kentucky Geological Society was another enjoyable and profitable Association gathering. Fourth in the recent series of mid-year meetings, it admirably maintained the character of the regional geological conference which has met the need of the members since the vigorous resumption of peace-time exploration and production. The registered attendance was 475.

Such a mid-year conference, concentrated on a defined area, affords opportunity for review of developments and presentation of details in a manner less hurried than possible at the large annual convention. The mid-year meeting possesses, potentially, the features of a round-table discussion or a refresher course, in a specified petroliferous province.

All of the program activities of the St. Louis meeting were efficiently arranged on the spacious and well appointed mezzanine of the Jefferson Hotel. Twelve commercial exhibitors of oil-field services and equipment had floor space opposite the elevators and the registration counter which was conveniently placed at the entrance to the Gold Room where the program papers were presented.

The printed program, a copy of which was handed each person who registered (there

was no registration fee), contained: the personnel of the Association officers, the officers of the two host societies, and the arrangements committees; an index map and skeleton structure section of the Eastern Interior basin, and generalized stratigraphic columns for southern Illinois and for Michigan; a schedule of events; and the technical program, including the abstracts of papers. The schedule of events is reprinted herewith.

TUESDAY, JANUARY 13, 1948

1:00 P.M. Registration. Members and guests should register promptly on arrival and are requested to purchase luncheon and dinner-dance tickets at this time.
5:00–9:00 Smoker, Crystal Room. Compliments of Ashland Oil and Refining Company, and C. E. Brehm, Fred A. Christanelli, Baroid Sales Division, National Lead Company, Entertainer.

WEDNESDAY, JANUARY 14, 1948

9:30 A.M.–12 Noon. General technical session, Gold Room. Presiding, M. M. Leighton, chief, Illinois Geological Survey.
9:30–9:35 Address of welcome. E. E. Rehn, president, Illinois Geological Society.
9:35–9:45 Response. C. E. Dobbin, president, American Association of Petroleum Geologists.
9:45–9:50 Brief remarks by Bailey Willis, distinguished guest, Leland Stanford University.
12 Noon. Luncheon, Ivory Room. Speaker, "Why Didn't I Think of That?" Earl B. Noble, past-president, A.A.P.G., Los Angeles, California.
2:00–4:30 P.M. General technical session, Gold Room.

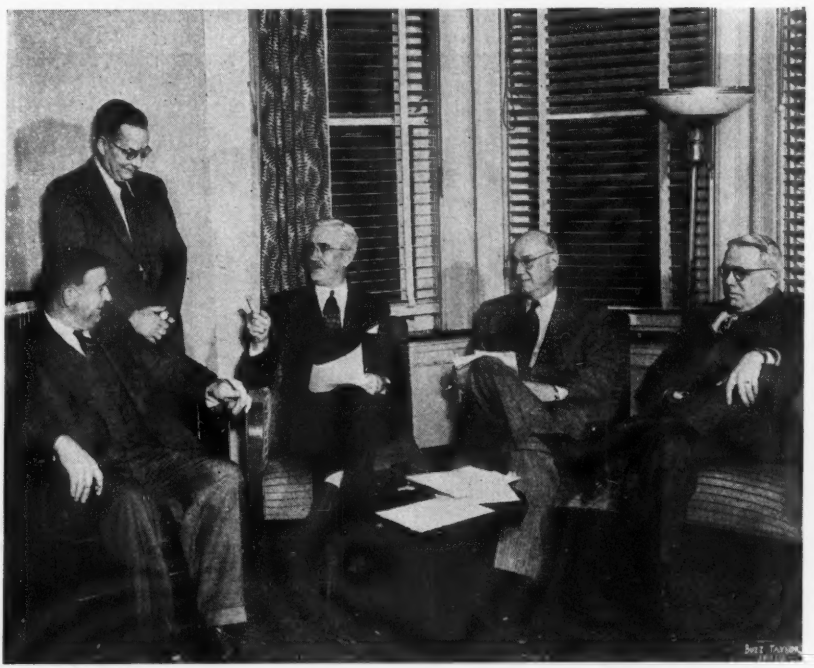

FIG. 1.—Executive committee in session at St. Louis, Missouri, January 13, 1948. Left to right: vice-president George S. Buchanan, editor Clarence L. Moody, president Carroll E. Dobbin, past-president Earl B. Noble, secretary-treasurer J. V. Howell.

FIG. 2.—Eastern Interior regional meeting, registration business.

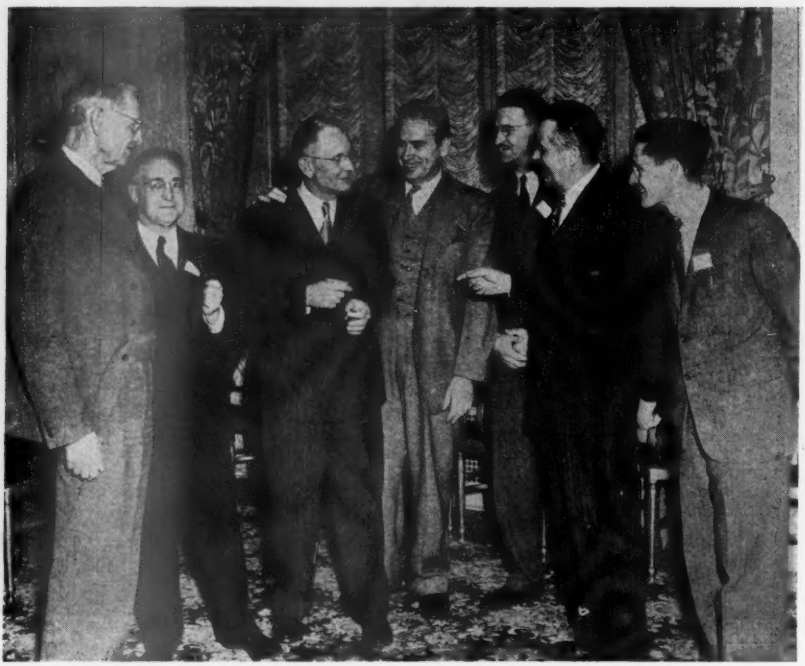

FIG. 3.—Conversation. Moran, Hager, Green, Speed, Lindberg, Grohskopf, Workman

THURSDAY, JANUARY 15, 1948

9:30–11:55 A.M. General Technical Session, Gold Room.
11:30 A.M. Ladies entertainment. Assemble in Room No. 1, Jefferson Hotel, where you will be met by a committee. Adjourn to Stix, Baer and Fuller department store for "Behind-the-scenes tour," luncheon, and style show as guests of Illinois Geological Society and Indiana-Kentucky Geological Society.
1:30–4:00 P.M. General technical session, Gold Room.
5:00–7:00 P.M. Cocktail party, Ivory Room. Hosts: Sohio Petroleum Company and E. A. Obering.
7:00 P.M. Dinner-dance Gold Room. Dress optional.

The names of the officers of the two affiliated societies sponsoring the meeting and the chairmen of the committees in charge of arrangements are here recorded.

ILLINOIS GEOLOGICAL SOCIETY

E. E. REHN, Mt. Vernon, Illinois.....President
C. E. BREHM, Mt. Vernon, Illinois.....Vice-president
C. DOH, Mattoon, Illinois.....Secretary-treasurer
JACK HIRSCH, Mattoon, Illinois.....Past-president

FIG. 4.—Bailey Willis, Stanford University, California, distinguished guest and fellow geologist at St. Louis A.A.P.G. meeting.

FIG. 5.—A table at the dinner-dance, St. Louis mid-year meeting.

INDIANA-KENTUCKY GEOLOGICAL SOCIETY

J. ALBERT BROWN, Owensboro, Kentucky.....President
G. E. TAYLOR, Evansville, Indiana.....Vice-president
P. L. KELLER, Evansville, Indiana.....Secretary-treasurer
C. W. HONESS, Evansville, Indiana.....Past-president

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C. E. BREHM: entertainment
CHARLES A. DOH: finance
G. O. RAASCH: exhibits
HARRY H. NOWLAN: reception
THEODORE G. GLASS: hotels

ABSTRACTS

1. DORSEY HAGER, consulting geologist, Centralia, Illinois, "Tectonics of North-Central States."

The large Interior Coal basin is divided into three parts: the Indiana basin, the Illinois basin, and the small Kentucky basin. In the Indiana basin, both northeast and northwest trends are important. North- and northeast-striking folds produce most of the oil in the Illinois basin, although several marked northwest-striking folds and faults are productive, particularly on the La Salle anticline—a very important feature. Northwest-striking folds and faults predominate in the Michigan basin.

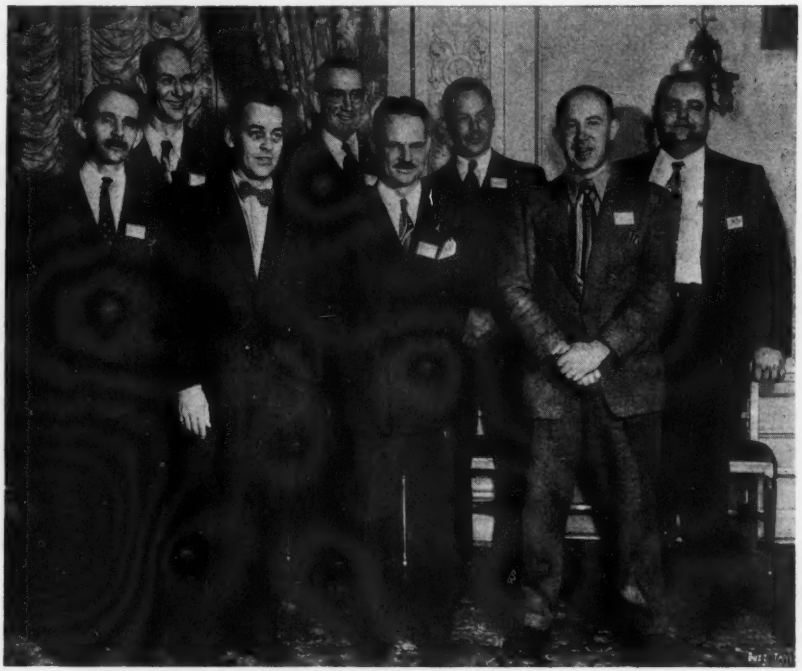

FIG. 6.—Eastern Interior regional meeting, St. Louis, January 14–15. Arrangements committee chairmen. Front row, left to right: G. O. Raasch, Illinois Geological Survey, exhibits; Gene Gaddess, Pure Oil Company, publicity; E. E. Rehn, Sohio Petroleum Company, general chairman; C. Doh, Schlumberger Well Surveying Corporation, finance. Back row, left to right: Stanley G. Elder, Sun Oil Company, program; Harry H. Nowlan, consultant, reception; T. G. Glass, Eason Oil Company, hotels and housing; Carl Bays, Illinois Geological Survey, technical equipment. Not present: T. E. Wall, registration; C. E. Brehm, entertainment.

In Kentucky, north- and east-trending folds and faults are the important features governing oil production. In Missouri, northwest- and north-trending folds govern the gas and oil production. In Iowa, as yet non-productive of gas or oil, northwest folding predominates, although the Redfield anticline which strikes northeast is a marked feature.

All the prominent uplifts, anticlines, domes, and faults in this area were largely in their present forms not later than the end of the Appalachian revolution—late Permian.

Minor folding which largely controls the gas and oil accumulations between and around the main uplifts has been influenced by stresses developed by the huge uplifts, and by stresses set up in the great basins. Most of the folding tends to follow earlier movements.

No comprehensive analysis of the tectonics of the area can be made until the detailed historical geology has been determined. It is essential to know the earlier local deformations; the old shore lines; which formations are competent and which are incompetent; and to have a definite idea of the relative stresses developed by the different uplifts. The stresses from Laurentia, Appalachia, Llanoria, and Cascadia have generally been taken for granted as causing the folds and faults, but local stresses have undoubtedly been developed by the Ozark, Sioux, Wisconsin, and the Ontario uplifts, and by action in the basins between them.

The Shawneetown-Rough Creek fault mosaic is an exceptional feature. Hicks dome and the Welles Creek disturbance, both probably crypto-volcanoes, are probably related to the volcanic action which was earlier than the first faulting. The important mineralization of the faulted area came after the first faulting, and prior to the second faulting. Earthquakes within historical time are evidence of continued slipping along some of the faults in the Mississippi embayment.

FIG. 7.—Technical session, Gold Room, Jefferson Hotel. Eastern Interior regional meeting. St. Louis, January 14.

FIG. 7.—Technical session, Gold Room, Jefferson Hotel. Eastern Interior regional meeting. St. Louis, January 14.

FIG. 8.—Dinner-dance, St. Louis mid-year meeting, Gold Room, Jefferson Hotel.

2. J. Marvin Weller and L. E. Workman, Illinois State Geological Survey, Urbana, Illinois, "Structural Development of Eastern Interior Basin."*

Much of the early Paleozoic history of the Eastern Interior basin is obscure because of the general lack of drilling to pre-Cambrian rocks. From earliest Paleozoic time, however, a gentle slope seems to have been present southward from Wisconsin. The Ozark region also appears to be a very ancient positive area that has been periodically subject to differential uplift.

Slow subsidence may have occurred during the Cambrian in the Eastern Interior basin but at that time the basin was probably only a part of a much larger basin that extended eastward to Appalachia and southward for an unknown distance.

The first evidence of important structural disturbance is provided by the unconformity at the base of the St. Peter sandstone which overlaps progressively older Ordovician and Cambrian formations in northern Illinois and southeastern Wisconsin. It appears to be related to the uplift of a northwest-southeast arch extending through southeastern Wisconsin, more or less in line with the Kankakee arch as the latter occurs in northwestern Indiana. This movement may have been an early stage in the separation of the Michigan and Eastern Interior basins.

At the end of Ordovician time there was sufficient uplift to permit deep erosion of the Maquoketa formation near this arch and also along the borders of the Ozark uplift and the Mississippi River arch. This can be interpreted either as broad regional doming with the principal erosion on the borders of the domed area or as differential uplift and erosion of the borders of a basin which was an early expression of the Eastern Interior basin.

Silurian sedimentary rocks in the basin provide little evidence of important structural changes. Cayugan strata, however, are absent in most if not all of the eastern Interior basin, although present in considerable thickness in the Michigan basin.

Beginning in late Silurian or early Devonian time, a broad gentle transverse uplift, the Pana arch, restricted lower Devonian deposits on the southeast, separated Middle Devonian limestones on the northwest and southeast, and restricted Kinderhook deposition mostly on the northwest. It may have had some effect on the character of Osage sediments.

Slow general subsidence of the Eastern Interior basin, which extended an unknown distance toward the south, occurred during Mississippian time, and was perhaps somewhat accentuated in Chester time. Although first evidence of the LaSalle anticline may be indicated in early Mississippian strata, most of the structural features of the present basin were initiated at the close of the Mississippian and developed progressively throughout the Pennsylvanian period. These features include the DuQuoin axis, which is the structural boundary between the basin and the Ozark area, the major LaSalle anticlinal zone, and numerous smaller structures.

Strata deposited throughout the Paleozoic thicken generally southward so that no southern boundary of the depositional basin is indicated. The present southern boundary was produced by uplift, accompanied by faulting, in southern Illinois and western Kentucky at the close of the Paleozoic era. There is scant evidence of subsequent important structural movement in the basin.

* Published with the permission of the chief of the Illinois State Geological Survey, Urbana, Illinois.

3. Elwood Atherton and David H. Swann, Illinois Geological Survey, Urbana, Illinois, "Correlations of Chester Series in Illinois and Indiana."*

The lower Chester formations are correlated in western Illinois, the subsurface of the southeastern Illinois basin, Hardin County, Illinois, and Indiana. The correlation of the western Illinois formations is based on unpublished work by Frank E. Tippie. The Paint Creek of southern and western Illinois is divided into three members: (1) an upper limestone and shale zone, named the Ridenhower member, and correlated with the "Paint Creek" of southeastern Illinois; (2) a middle sandstone and shale zone, correlated with the Bethel sandstone of southeastern Illinois; and (3) a lower "pink crinoidal limestone" correlated with the upper part of the "Renault" formation and called the Downeys Bluff member in southeastern Illinois. The remainder of the "Renault" formation in southeastern Illinois is referred to as the Shetlerville member of the Renault formation. In its upper part it includes a sandstone which is correlated with the subsurface "Benoist sand" of the western part of the Illinois basin and possibly the Yankeetown of western Illinois. Sections prepared by Tippie show that the Aux Vases formation may be confined to western Illinois.

The "Aux Vases" and "Rosiclare" of the subsurface in southeastern Illinois are correlated respectively with the Rosiclare and Spar Mountain (sub-Rosiclare) of Hardin County, Illinois.

The correlations of lower Chester formations of Illinois with those of Indiana are shown.

* Presented with permission of the chief of the Illinois State Geological Survey.

4. STUART K. CLARK AND JAMES S. ROYDS, Continental Oil Company, Ponca City, Oklahoma, "Structural Trends and Fault Systems in Eastern Interior Basin."

The Eastern Interior basin is a structural basin cradled between the Ozark uplift and the Cincinnati arch-Nashville Dome uplift.

The two most conspicuous structural features indicated by an areal geology map are the La Salle anticline and the nearly separated lobe of the basin in Kentucky.

A cross section indicates that the area acquired its basin character early and retained it through most of geologic history.

A study of the folding and faulting within the basin reveals two different types of structure.

One consists of a series of faults trending S. 20° W. and paralleling lines of anticlinal folding. Cross sections show these faults to be "normal diagonal shears" and the folds to be similar to the "granite ridge" and related lines of folding in the Mid-Continent area.

The other is the Shawneetown-Rough Creek fault zone and associated faults extending across the south end of the basin. Cross sections and data gleaned from the record dealing with this and the Kentucky River fault zone, to which it appears closely related, show this to be a type of faulting entirely different from the system first described. The authors suggest an explanation and a classification different from any proposed in the past.

5. ALFRED H. BELL, Illinois State Geological Survey, Urbana, Illinois, "La Salle Anticlinal Belt, Illinois."

The La Salle anticlinal belt in Illinois extends from Rock River in the vicinity of Oregon, Ogle County, south-southeasterly to Wabash River near St. Francisville in Lawrence County, a distance of about 260 miles. The north end of the La Salle anticlinal belt is in an area of complex structure in which several structural axes converge. At the south it fades out into the Indiana part of the Illinois structural basin.

The La Salle anticlinal belt is the site of one of the major oil accumulations of this country, the Southeastern Illinois oil field, located along its southernmost 65 miles. Total production to date has been 458,000,000 barrels of oil. The present production rate after 42 years of production is approximately 4½ million barrels a year. Approximately 19,307 oil- or gas-producing wells have been drilled in a total oil-producing area of 97,435 acres; of these approximately 10,878 wells are still producing.

The principal producing sands are Mississippian and Pennsylvanian in age. Small amounts of oil have been obtained from Devonian and Ordovician limestones in limited areas. Numerous dry holes have been drilled to the Devonian and deeper formations; a few reached the St. Peter sandstone.

It seems probable that the La Salle anticlinal belt has already had the greater part of its drilling development. The most promising future possibilities appear to be for stratigraphic traps on the flanks. Secondary-recovery methods, both repressuring and water-flooding, which are yielding substantial quantities of oil in limited areas of the Southeastern Illinois field, have great possibilities for future expansion.

6. DARSIE A. GREEN, Pure Oil Company, Olney, Illinois, "Oil Fields on Noble Anticline, Jasper, Richland, Clay, Wayne Counties, Illinois."

This discussion pertains to the oil fields on a major anticline, the axis of which extends northeast and southwest through parts of four counties in the Illinois basin. The direction of this axial trend in Richland and Clay counties varies 45° from the axial trend of the LaSalle anticline in Lawrence County. This anticline disappears into the normal dip on the flank of the LaSalle anticline in northeastern Jasper County and can not be interpreted as a branch of the larger structure.

Published papers by Theron Wasson and by Lynn K. Lee have related the history of the discovery of the structure by the reflection seismograph; the early drilling explorations; the early field developments; and have given the detailed descriptions of the producing formations. Nearly 9 years have elapsed since the latter of those papers were presented to the Association at the Oklahoma City convention in March, 1939. During these years continuous drilling operations have added enough new information to justify this supplement to the previous papers.

For lack of a better term, Lynn K. Lee referred to this anticline as the "Basin" anticline. Now that numerous productive anticlines have been developed in a wide area in the Illinois basin, it seems appropriate to give this structure a more localized geographic name. The term "Noble" is here suggested for that name, Noble being a well known town on the axis of the anticline in western Richland County.

The first slide shows the Noble anticline with 100-foot contours and shows its structural and geographic relations to folds on the LaSalle anticline on the east and the Louden and Salem anticlines on the west. The second slide shows the Noble anticline with 50-foot contours and the areal extent of the several oil fields on the anticline. Other slides and the discussion pertain to the irregular occurrence of some of the Chester sand pools in the various fields, and the erratic occurrence of some of the Ste. Genevieve limestone oil reservoirs.

7. J. V. HOWELL, consulting geologist, Tulsa, Oklahoma, "Benton Pool, Franklin County, Illinois."

The Benton pool was opened in January, 1941, and developed so rapidly that practically the entire area was drilled by the end of the year. Oil is produced from the Tar Springs sandstone at 2,000–2,100 feet. Accumulation is controlled by a northward-trending anticline with limited closure, but with abrupt graduation of sand to shale at the south, or critical side. Effective sand thickness is as great as 62 feet and the average for the field is 42 feet. Deeper sands have not been tested.

To June 1, 1947, the field had produced 18,656,892 barrels, and for the month produced 2,123 barrels per day. Two hundred forty-two producing wells were completed, of which three have been plugged. The recovery to date has been slightly more than 77,000 barrels per well for each productive well drilled.

Most of the wells have been drilled through abandoned, active, and projected coal mines, and the special methods used are discussed, as well as the history of discovery, reservoir conditions, and sand conditions.

8. J. PETER SMITH, Carter Oil Company, Carmi, Illinois, "Pressure-Maintenance Problems in Dix Pool, Illinois."

The Dix pool, in northwest Jefferson County, Illinois, produces chiefly from the Bethel sand. From its discovery in early 1938 until the middle of 1945, bottom-hole pressures were kept above reservoir-saturation pressure. Because of the influence of Bethel production in the Boyd pool discovered in the summer of 1944 and located 2 miles southwest of Dix, the bottom-hole pressures at Dix began to approach the reservoir-saturation pressure.

Since it was not advisable to restrict production to a point that would maintain satisfactory pressure, a program for the drilling of water-injection wells for the purpose of pressure maintenance is now underway at Dix.

9. C. DOH, Schlumberger Well Surveying Corporation, Mattoon, Illinois, "Geology of Mattoon Field, Illinois."

The interesting features of the Mattoon field are: (1) the history of its discovery; (2) the dual-completion methods used; and (3) the very lenticular condition of its sands.

1. The Mattoon anticline in Coles County—180 miles south of Chicago—was generally known in 1937. The first well, drilled in 1939, made a total of 132 barrels. In 1940, four more wells, with only one producer (the discovery well), had practically condemned exploitation in spite of the verification of the structure. Three years later a small well extended the potential field and was followed by a series of mediocre wells.

In 1945, or five years after the discovery well was completed, an independent operator completed a 100-barrel well, ¾ mile from the discovery, renewing the general interest. A boom soon developed when a well was completed, producing 1,200 barrels. Rapid extensions defined a potential area of 7,000 acres, a major field.

2. Wells in the two main shallow producing sands, less than 2,000 feet deep, soon were dually completed with successful results. The Cypress sandstone, with as much as 40 feet of saturation, produced with the more commonly developed Rosiclare sand and sandy limestone. A 7-inch oil string was set on the top of the lower sand with aluminum pipe opposite the Cypress sand. Both sands were shot with nitroglycerine, tested individually by setting a temporary, drillable plug, and produced together.

Wells are drilled to 2,000 feet in 7 days, with two rock bits and four retips. However, the dual completion takes 20 days of spudder time. Average total cost of single completion is $15,000. The dual method increases the cost to $18,000.

Electric logs were made on all wells and gave good quantitative results. One problem could not be solved by electric logs: differentiation between gas and oil in the Cypress. However, a gas-oil level was determined by drill-stem tests on the crest of the structure.

Within 14 months 114 wells had been drilled, of which 22 were dry holes and 92 were producers, with an average initial production of 148 barrels. Peak production was reached in June, 1946, with 15,500 barrels daily. Steady decline was experienced during the next 12 months, and in June, 1947, the daily production was down to 5,500 barrels daily. Total recovery from 5,500 producing acres is estimated at 17 million barrels.

3. Detailed electrical-log cross sections are presented to show the extremely lenticular condition of the sands. A considerable area on the top of the structure remains undrilled. A gas cap in the upper Cypress sand has not been exploited. The west part of the City of Mattoon also remains undrilled due to communitization problems, in spite of its potential productivity.

The Aux Vases sand was found extremely shaly, excepting the southwest part of the field. Its development, estimated at only 50 acres, will produce approximately 6,000 barrels.

Six Devonian wells on the structure have produced only 1,100 barrels of oil. However, potential production from the Devonian can not be ignored at this time.

The total accumulated production of the Mattoon field on September 1, 1947, is 6,280,000 barrels.

10. EDWARD J. COOMBS, Sun Oil Company, Evansville, Indiana, RALPH E. ESAREY, Indiana University, Bloomington, Indiana, "Subsurface Correlations of Lower Silurian Formations in Southern Illinois and Indiana."

Silurian lithology and correlation in southern Illinois and Indiana are discussed, with particular reference to the Bainbridge limestone and related beds.

The Bainbridge formation of southeastern Missouri represents the Niagaran sediments of this area. The average thickness of the formation along the outcrop in Missouri is about 130 feet. Eastward in the subsurface of Illinois thicknesses of 200 feet or more are found.

The Niagaran of southeastern Indiana includes the Louisville, Waldron, Laurel, and Osgood formations. These formations total about 80 feet in thickness at the outcrop and thicken to more than 200 feet in southwestern Indiana.

Lithologic and electric-log characteristics are discussed, along with criteria for subsurface identification.

Cross-section studies trace the Silurian beds from their outcrop in Missouri through the subsurface of Illinois and Indiana to the outcrop along the Cincinnati arch. Correlations are based essentially on lithologic and stratigraphic relationships.

11. E. A. OBERING, Mt. Vernon, Illinois, "St. Jacob Field, Madison County, Illinois."

The St. Jacob field, on the west flank of the Southern Illinois Coal basin 23 miles east by northeast of St. Louis, Missouri, was discovered in May, 1942. Accumulated production on October 1, 1947, was 1,847,966 barrels of oil and the average production during September was 567 barrels of oil daily from 48 wells. The field is on 20-acre spacing and the productive area covers approximately 1,000 acres. The oil occurs in porous zones in the Trenton (Kimmswick or Galena) limestone formation, and the wells are completed at an average depth of 2,370 feet.

The St. Jacob field comprises two distinct pools separated by a pronounced saddle and characterized by differences in oil-water contact levels, reservoir energy, volume of water, and corrosive nature of the water.

The structure of the north pool is a dome-like anticline, slightly elongate east-northeast and west-southwest, and the structure of the south pool is an asymmetrical anticline with north and south elongation. Reverse or west dip of 186 feet has been established on the south anticline which is an indication of the amount of closure.

The strata below the Pleistocene till or glacial drift are represented by the following sequence of beds in descending order: the Pennsylvanian series, the Upper Mississippian or Chester series, the Lower Mississippian including the St. Louis limestone, Salem limestone and Osage group, the New Albany shale, the Devonian limestone, the Silurian limestone and dolomite, the Maquoketa shale, and the Trenton (Kimmswick or Galena) limestone.

12. L. E. WORKMAN AND ALFRED H. BELL, Illinois State Geological Survey, Urbana, Illinois, "Deep Drilling and Deeper Possibilities in Illinois."*

During the 4 years, 1944 to 1947, fifteen oil test wells were drilled in Illinois to the St. Peter sandstone, of which twelve penetrated to various formations below the St. Peter, one reaching the basement rocks.

Isopach maps of various formations between the St. Peter sandstone and the basement rocks, supplemented with cross sections, show the influence of the Ozark and Wisconsin positive structural areas. Notable variations in the stratigraphic sequence are the disappearance of the Galesville sandstone and the introduction of an oolitic limestone in the Cambrian strata in central Illinois.

Maps show the structure of the Illinois basin on the top of the St. Peter sandstone and the general configuration of the basement surface so far as known. Isocons on the St. Peter map show the total mineral content of water in the St. Peter sandstone.

Some of the geologcial factors that should be considered in prospecting for oil in these deep strata are discussed.

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13. C. A. BAYS[1], R. C. COOPER[2], F. W. MITCHELL[3], G. W. PRESCOTT[4], AND C. K. RUDDICK[5], "Electrical Well Logging in Illinois Basin."

Electrical logging has been widely used in the exploration and development of the Illinois basin oil fields of Illinois, Indiana, and Kentucky. Standard logging techniques have evolved during the decade of activity in the basin.

[1] Illinois State Geological Survey, Urbana, Illinois.
[2] Sinclair Wyoming Oil Company, Evansville, Indiana.
[3] Consulting Geologist, Mt. Carmel, Illinois.
[4] Illinois State Geological Survey, Urbana, Illinois.
[5] Schlumberger Well Surveying Corporation, Mattoon, Illinois.

The relations of electrical values to formation fluids, lithology, porosity and permeability, drilling fluids, and hole diameter are discussed.

Electrical logs have furnished valuable records of the wells drilled. They have formed the basis for much of the stratigraphic and structural work in the territory. Recognition of commercial saturation in wells and prediction of reservoir behavior have been successful in some cases by integration of electrical log data with core and production information. The electrical log has been a valuable tool in guiding completions.

The available electrical-log information on the wells of the Illinois basin promises additional future value in further exploration and secondary-recovery operations.

14. HOMER C. MOORE, Oil Exploration, Inc., Tulsa, Oklahoma, "Seismic Comments, Illinois Basin."

This is a short generalized discussion of some improvements in seismograph instruments and their use in shooting in the Illinois basin. Mention is made of the importance of weathering interpretations, the need of sufficient control in localizing small structures, and the necessity for cooperation of geologist and geophysicist.

15. JAMES B. MACELWANE, St. Louis University, St. Louis, Missouri, "Seismicity of Mississippi Valley."

Seismicity and the factors which govern it are not readily susceptible to quantitative definition and determination even under the best conditions. The seismicity of the Mississippi Valley in particular has been under observation too short a time in general, and in particular by means of seismographs it has been studied at too few points even in recent years to allow more than a qualitative and sketchy assessment. The area may be divided in general into several provinces such as the upper, middle, and lower Mississippi Valley, the Gulf Coast, and the larger tributary valleys.

16. DONALD G. SUTTON, Sun Oil Company, Evansville, Indiana, "Geology of Uniontown Pool, Union County, Kentucky."

The Uniontown pool in northern Union County, Kentucky, discovered in September, 1942, produces mainly from the Waltersburg, Tar Springs, and Cypress sandstones of the Chester series, Upper Mississippian system. It produces in a minor way from a sandstone of Pennsylvanian age and from the Palestine and Hardinsburg sandstones and the Menard limestone of the Chester series.

The structure consists of an elongate dome, the western side of which is closed against the upthrown side of a normal fault.

There are 229 producing wells in the field, which had produced 8,600,000 barrels of oil to October 1, 1947. The producing area covers approximately 2,000 acres.

17. H. H. BYBEE, Carter Oil Company, Mattoon, Illinois, "Hitesville Consolidated Pool, Union County, Kentucky."

The Hitesville Consolidated pool is on a broad elongate anticline trending north and south, 4½ miles north of the Shawneetown-Rough Creek fault system in Union County, Kentucky, at the southern extremity of the Illinois basin. The pool was discovered in February, 1943, and has expanded to include approximately 3,500 productive acres. The Chester produces from the Waltersburg, Tar Springs, upper and lower Cypress, and Aux Vases sands. The Ste. Genevieve produces from seven separate porous McClosky zones. Sixty-one per cent of the wells in the pool produce from the McClosky and 20 per cent from the Cypress. The multiple zones of McClosky production constitute the outstanding feature of the pool.

18. ILEY B. BROWNING, Consulting, Ashland, Kentucky, "Slaughters Oil Pool, Webster County, Kentucky."

This description of the Slaughters oil pool includes: (1) extent of the development; (2) the geology of the field in detail, with emphasis on the faults, their structure, and relation, and effect on the accumulation of oil and gas, and (3) the producing formations with production figures to date.

In conclusion the relation of this structure to the general structure of the area and the probability of its extent and bearing on other development south of the Shawneetown-Rough Creek fault are discussed. Slides and maps illustrate the principal features.

19. W. L. EFFINGER, The California Company, New Orleans, Louisiana, "Geology of Two Recent Deep Tests in Kentucky and Tennessee."

In 1946–1947 two deep tests, one on the Cincinnati arch in Kentucky, and one on the Nashville dome in Tennessee, were the first wells to penetrate the entire sedimentary section in this geologic province.

The California Company's A. R. Spears No. 1, located 1.7 miles northwest of McKinney, Lincoln County, Kentucky, reached the total depth of 6,117 feet, stopping in rhyolite porphyry, probably pre-Cambrian in age. This test was drilled on a local anticline on the south plunge of the Cincinnati

arch. Starting in the lower part of the Tate formation of the upper Ordovician, the well penetrated 418 feet of argillaceous limestones and shales of upper Ordovician, Maysville, Eden, and Cynthiana groups; 191 feet of middle Ordovician, Lexington limestone; 651 feet of lower Ordovician, Wells Creek dolomite; 2,936 feet Cambro-Ordovician dolomite probably more or less equivalent to the Knox dolomite group of Tennessee; 137 feet of Cambrian limestone and dolomite with minor amounts of gray shale tentatively correlated with the Maynardville limestone; 739 feet of Cambrian reddish brown and gray shales with some fossil fragments, and gray interbedded siltstones, considered to be in part correlative of the Nolichucky formation; 615 feet of quartzitic sandstone with intercalated green and gray shales and siltstones that may be middle or lower Cambrian in age; 25 feet of Cambrian or pre-Cambrian limestone, the lower part containing pebbles of rhyolite; and 356 of rhyolite porphyry, probably pre-Cambrian in age.

The California Company's E. W. Beeler No. 1, located ½ mile southwest of Campbellsville, Giles County, Tennessee, reached the total depth of 5,750 feet, stopping in granite, probably pre-Cambrian in age. This well is on a prominent local closure on the southwestern extension of the axis of the Nashville dome. Starting in limestone of the Carters formation of the middle Ordovician, this well penetrated 660 feet of middle Ordovician, Black River-Stones River limestone; 69 feet of lower Ordovician, Wells Creek dolomite; 4,571 feet of Cambro-Ordovician dolomite probably correlative of the Knox and Bibb-Ketona-Brierfield groups; 338 feet of Cambrian calcareous and shaly dolomite; 77 feet of quartzite and quartzitic sandstone, Cambrian or pre-Cambrian in age; and 45 feet of granite.

20. REX P. GRANT, Department of Conservation, Lansing, Michigan, "Recent Developments in Western Michigan."

The Western Michigan district comprises seven counties in the west-central part of the state. The district includes the area from Muskegon, north to Manistee, west to Cadillac, and south to the vicinity of Big Rapids. The area is fortunately situated as regards transportation facilities, being served by four Lake Michigan ports and a network of railroads and highways.

Although one of the major pools of the state, the Muskegon pool, was discovered in this district in 1927, the area apparently was not very attractive to the operating companies and development until recently has been slow. Other fields in the district are Hart, discovered in 1932 but now abandoned, Ravenna gas field in 1936, Dalton in 1940, Sauble in 1942, Woodville and Goodwell in 1943, Stony Lake in 1946, and Kimball Lake in 1947. All oil fields produce from the Traverse (Devonian) limestone; Muskegon also produced from the Dundee (Devonian) limestone. The Ravenna gas field produces from the "Berea," a sandy limestone member of the Ellsworth (Mississippian) formation.

Stony Lake field, Oceana County, was discovered in December, 1946, by the Carter Oil Company. During 1947 the field was expanded to 26 wells which, by November 1, had produced approximately 275,000 barrels of oil. The field has been developed on a spacing pattern of one well to each 40-acre unit, with wells drilled in the northeast corner of each unit. The Kimball Lake field, Newaygo County, discovered by the Sun Oil Company in February, 1947, had produced by November 1, approximately 619,000 barrels of oil from 82 wells. The field is being developed on a diagonal 20-acre pattern; the wells are drilled in the northeast and southwest corners of 40-acre units. Both fields were located by core drilling. Their discovery has resulted in a renewal of interest and vigorous exploration in western Michigan.

21. GEORGE V. COHEE, United States Geological Survey, Ann Arbor, Michigan, "Lower and Middle Silurian Rocks in Michigan Basin."*

The discovery of the Howell gas field, Livingstone County, Michigan, with gas production from the base of the Salina formation and the top of the Niagara group, has added to the interest in the possibility of commercial production from these rocks in other areas in the Michigan basin. Gas and oil have been produced from the Cataract formation and Niagara group in fields in southwestern Ontario for many years, and showings of oil and gas were reported in Niagara rocks penetrated by wells in various areas in Michigan.

Cataract rocks of lower Silurian age and Niagara rocks of middle Silurian age occur in the subsurface in the Michigan basin, and they crop out, or underlie glacial drift, around the margin of the basin. The rocks are exposed in places in the Northern Peninsula of Michigan, eastern Wisconsin, northeastern Illinois, northern Indiana, northwestern Ohio, and southwestern Ontario, Canada.

The Cataract formation which includes the "White Medina" and "Red Medina" gas-producing sandstones in Ontario west of Niagara River, is 45–190 feet thick in the Michigan basin. The Cataract is represented by dolomite and shale in the Michigan basin, and sandstones of the eastern facies are absent.

The Niagara group of the Michigan basin is composed almost entirely of dolomite, with some chert and shale in places. Shale, which grades laterally into dolomite, occurs in the group in northern Indiana. The lower part of the Niagara in eastern Michigan and the Northern Peninsula of Michigan

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is dolomite, argillaceous dolomite, and shale. The thickness of the Niagara varies from 66 feet in Kent County in southwestern Michigan to more than 700 feet in Mackinac County in the Northern Peninsula of Michigan. The Niagara increases in thickness southward from Kent County, Michigan, to 425 feet in northwestern Indiana near the area of outcrop. The sequence of Niagara rocks in southern Michigan is thin due to non-deposition of pre-Salina erosion. Outcrop and subsurface data indicate that pre-Salina erosion occurred in some areas. Local variations in thickness are due in part to reefs which in places are numerous. Niagara rocks dip at the average rate of 45 feet per mile from the outcrop area in northern Indiana to the center of the Michigan basin in Clare and Gladwin counties, Michigan, where the top of the group is more than 9,000 feet below sea level. The average dip per mile from the outcrop area in the Northern Peninsula to the center of the basin is approximately 70 feet per mile.

22. R. H. WOLCOTT,* Sohio Petroleum Company, Mt. Pleasant, Michigan, "Coldwater Field, Isabella County, Michigan."

The Coldwater field, discovered in August, 1944, is in the central part of the Lower Peninsula of Michigan, a few miles west of the center of the Michigan structural basin. The principal producing zone is the Rogers City (Devonian) dolomite. A typical Rogers City dolomite field, it has a producing closure of 55 feet covering an area of 3,160 acres. A greenish amber oil of 48° A.P.I. gravity is produced from an average depth of 3,750 feet. The reservoir is a structural trap, anticlinal in nature, the major axis striking northwest-southeast parallel with the major axis of the basin and modified by a strong cross-fold at right angles to the major axis. An important reserve in the Michigan area, the original oil in place was estimated as 43,000,000 barrels, and the expected ultimate recovery more than 5,000 barrels per acre.

On the same anticlinal structure, at an average depth of 1,400 feet, the Michigan series 'Stray' sandstone (Mississippian) forms a reservoir for dry gas with a productive area of 2,400 acres.

The limits of the producing area are well defined and little drilling is foreseen for the future.

* The writer thanks T. S. Knapp, geologist, and the production department, Sohio Petroleum Company, for their contribution to this paper.

23. JOHN G. GROHSKOPF, assistant State geologist, Rolla, Missouri, "Zones of Plattin-Joachim of Eastern Missouri."*

Examination of cable-tool cuttings from water wells has resulted in the establishment of four zones in the Plattin and two zones in the Joachim. The zoning is based on lithologic character and insoluble residues. A cross section through fourteen selected wells extending approximately 300 miles, from Kirksville in northeast Missouri to Cape Girardeau in southeast Missouri, indicates the position and thickness of the zones where present.

At Cape Girardeau the Plattin is 600 feet thick and the Joachim is 250 feet thick. In the type areas, approximately 75 miles northwest, the Plattin and the Joachim are each only 200 feet thick. In northeast Missouri, in the vicinity of Kirksville, both formations are overlapped by the "Decorah," where the latter rests on the St. Peter. The cross section indicates that older beds are overlapped from southeast to northwest and suggests an unconformity at the base of the "Decorah."

Some of the subsurface zones have been located at the outcrop of widely separated localities and can be used in surface mapping. Redefinition of the Plattin-Joachim boundary is desirable. The name Rock Levee, derived from a place of that name approximately 3 miles southwest of Cape Girardeau and near the intersection of Federal Highways 25 and 61, is proposed for the rocks lying between the redefined Plattin and Joachim. The term "Decorah" as used in Missouri requires more specific definition.

* Published by permission of Edward L. Clark, State geologist, Department of Business and Administration, Division of Geological Survey and Water Resources, Rolla, Missouri.

24. JOHN T. ROUSE, Magnolia Petroleum Company, Dallas, Texas, "A Challenge to A.A.P.G. Research."

Last summer the A.A.P.G. research program in sedimentology was presented for the consideration of the A.P.I. advisory committee on fundamental research. After due deliberation that committee recommended that the A.P.I. should sponsor specific projects within that portion of the program dealing with the origin and early diagenesis of sediments and their contained fluids.

The A.A.P.G. research committee has been holding all projects in abeyance until the A.P.I. decided which portions of the sedimentology program they wished to consider. Now the A.A.P.G. is free to go to work on any or all of the programs dealing with pre-Pleistocene sedimentary rocks.

The most important question before us is—What is the A.A.P.G. going to do? The committee feels that the Association now needs the cooperation of all local geological societies in formulating and completing a constructive and concrete attack on that part of the sedimentology program which

deals with pre-Pleistocene sedimentary rocks. Such a program would involve a detailed study of specific Paleozoic, Mesozoic and Tertiary formations on the outcrop and in the subsurface over wide areas. It is readily apparent that it would be extremely difficult to make a study of this kind without the active work and cooperation of the local geological societies.

THIRTY-THIRD ANNUAL MEETING, DENVER, APRIL 26–29, 1948

Thomas S. Harrison, chairman of the committee on arrangements, announces appointment of the following chairmen and co-chairmen to arrange the convention program and activities.

General Committee	Thos. S. Harrison, A. E. Brainerd
Technical Program	N. W. Bass, R. L. Heaton
Finance	H. W. Oborne, J. M. Kirby
Entertainment	C. E. Manion, K. L. Gow
Hotels	C. S. Lavington, Laurence Brundall
Registration	Robert McMillan, A. W. Cullen
Field Trips	J. W. Vanderwilt, F. M. Van Tuyl W. O. Thompson, P. G. Worcester, E. S. Shaw
Reception	E. W. Scudder, V. Z. Smith
Publicity	H. M. Crain, R. H. Volk
Exhibits	H. E. Christensen, C. R. McKnight
Service Detail	K. C. Forcade, E. G. Hurd
Transportation	George R. Downs, J. H. Turner
Society of Economic Paleontologists and Mineralogists	J. H. Johnson
Society of Exploration Geophysicists	C. A. Heiland
Women's Committee	Mrs. J. H. Johnson

The committee has completed its preliminary investigation of prospective attendance at the convention, and will soon send out a second card, requesting that the membership make choice of hotel accommodations and field trip preference.

N. W. Bass, chairman of the technical program, announces no papers can be included in the program later than February 20, due to restrictions by the printer.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS PREPARATION OF MANUSCRIPTS[1]

AUTHOR[2]
City and State

ABSTRACT

Helpful suggestions to authors issued by other scientific societies are here adapted to the requirements of the Association *Bulletin*. The arrangement is that of a correctly prepared manuscript. These abstracts should be prepared for all major papers submitted for publication and for all titles to be presented on Association programs. Abstracts should state all major and minor topics in which new facts are involved and should mention all conclusions reached. They must be brief.

[1] Read before the Association at the _____ meeting, _____ (date).
Manuscript received, _____ [date]. [This safeguards the author's priority.]
Published by permission of _____ [name of official or company].

[2] [Business or professional connection. Acknowledgment of assistance and thanks for criticism may be placed in this footnote.]

Introduction

It is taken for granted that authors of papers in the *Bulletin* desire to give all possible aid in achieving the highest possible publication standards and in lightening editorial burdens. Consideration of the suggestions presented here, and conformation to the arrangement and style of current papers in the *Bulletin* will assist very materially the work of the editorial staff. This outline is being published in the *Bulletin* in order that it may be readily available to all members. It is hoped that the instructions it contains will be helpful to those who contemplate the preparation of manuscripts.

Title of Paper

A title should be brief, and should not attempt to summarize the paper. The first word in a title should be an important one, and, if possible, one helpful in indexing the article. It is seldom desirable to begin a title with indefinite words such as "A," "The," "Notes," or with phrases such as "On the," "Some considerations," and similar expressions.

Writing

In the scientific writing, clearness and conciseness are of prime importance. Careful examination to see that what one desires to say is said without ambiguity or circumlocution, that construction is correct, and that sentences are neither too long and involved nor too short and choppy, will improve a paper greatly. Correction and criticism by a friend or colleague may be very helpful.

Usage of the *Bulletin* should be followed in preparing manuscript for publication in it. Generally, extreme abbreviations and the like are not good form: write 1,990 feet, not 1990′; well No. 3, not #3; Sec. 12, T. 6 S., R. 5 E., not 12-6-5 or 12-6S-5E. It is considered desirable to avoid use of the first person.

Typewritten Form

All contributions should be typewritten and preferably should be direct imprints rather than carbon copies. The task of marking a single-spaced manuscript for the printer is one of the most vexing to confront an editor. All manuscripts submitted for publication should, therefore, be double-spaced, or better still, triple-spaced; even tables and footnotes should not be single-spaced.

Headings

Outline.—Though a table of contents is not printed at the beginning of a published article, it is advisable to prepare carefully an outline to follow in writing the paper. The outline will make for desirable condensation and logical arrangement of the material; and its parts will constitute the headings of the topics in the text.

Rank.—Headings have first, second, third, or fourth rank, dependent on their relative importance. They have corresponding positions in the manuscript and certain styles and sizes of type are used by the printer for each rank of heading. Attention by the author to the rank of headings which are introduced will aid him in logical arrangement and presentation of his paper and will assist editor, printer, and reader.

Means of designation.—A first heading should be written in capitals midway across the page. A heading of a second rank may also be placed centrally as illustrated by the caption "Headings" at the beginning of this section; if so placed it is set by the printer in small capitals. If no headings of lower rank are used, it is common practice to place subordinate headings at the side as shown at the beginning of this paragraph.

Footnotes and References

Footnotes and references should be inserted at any place in the text where needed, continuous reference numbers being used, and the notation being made between two lines. References should be abbreviated and should follow the form used in current numbers of the *Bulletin*. The following[3] are typical, correctly arranged references.

[3] Frederic H. Lahee, "Exploratory Drilling in 1944," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 6 (June, 1945), pp. 629–45.

M. Grace Wilmarth, "Lexicon of Geologic Names of the United States," *U.S. Geol. Survey Bull. 896*, Pt. 2 (1938), p. 1455.

An exception to this arrangement is permissible if a long reference list in bibliographic form is printed at the end of the paper, in which case numbers are inserted thus (1) throughout the text, no other notations being used.

Illustrations

Importance.—Good illustrations are the heart and soul of many papers. No reasonable effort should be spared in making them effective. Fortunately, practically every geologist can, with care and patience, prepare entirely satisfactory drawings and other types of illustrations.

Title and location.—Each illustration should bear the author's name, the title, and amount of reduction desired, due regard being given to the size of the *Bulletin* page. The, position of each illustration in the manuscript should be indicated by writing the title across the page between two ruled lines, thus:

FIG. 1.—[Title of illustration; cut line which will be set in type below the cut.]

Legibility after reduction.—Because photographic reduction of about half size minimizes undesirable irregularities in drafting, illustrations intended for publication should, in general, be approximately twice the size in linear dimensions of the figure as it will appear in the *Bulletin*. Most important is forethought by the author concerning size and legibility after reduction. He may frequently find it helpful to examine his illustrations through the ground glass of a reducing camera. No printing should appear on the original drawing which after reduction will be less than 1/32 inch in height.

Preparations of drawings.—The *Bulletin* page available for illustrations is 6 inches wide and 9 inches long. All illustrations should be so prepared that they may be reduced to dimensions not greater than these and yet be perfectly legible. Illustrations so large or of such shape that it is necessary to fold them into the *Bulletin* are costly. Authors should, where possible, avoid them. Drawings should be in black, preferably India ink on tracing cloth. Colored illustrations can be used only under the most exceptional circumstances. Black-line prints, if clear, make satisfactory "copy." Photostat copies of drawings are generally "muddy" or blurred and are not desirable for reproduction. Where cross-section paper is used, it is important to take into account the effect of reduction on the appearance of a graph; a fine-ruled paper is undesirable, and even a coarse-ruled paper may give an unsatisfactory result on reduction. It is perhaps best to prepare a graph on tracing cloth, ruling in only the lines desired in the published figure. Orange, red, blue, and green lines photograph black. A graphic, bar scale, for miles or feet, should be drafted on maps. Failure of authors to consider some of these matters has caused expensive re-drafting.

Photographs.—Photographs should be very clear, show moderate contrast, and should be finished with a glossy surface. It should, perhaps, be frankly stated that the half-tone process used by the *Bulletin* to reproduce photographs is not entirely satisfactory where detail is required as, for example, in figuring new and little known species of fossils. The process, however, has certain advantages for the reproduction of the usual type of photograph published in the *Bulletin*.

Summary.—Planning of each illustration with the size and shape of the page in the *Bulletin* in view will improve greatly the appearance and value of the published figure.

Publication

Papers accepted for publication in the *Bulletin*, or for presentation at Association meetings, are the property of the Association. Members desiring prior publication of such papers in trade journals, or elsewhere than in the *Bulletin*, should submit to the business manager complete duplicate copies of the paper and the illustrations, together with the name of the periodical in which publication is desired. Papers printed in trade journals or elsewhere without having been submitted to the business manager are not eligible for publication in the *Bulletin*.

Conclusions

These simple suggestions are only a few of those which might, perhaps, be made, but it is hoped that they are sufficient to give prospective authors a general idea of the most desirable form for manuscript copy. Those who write for the pages of the *Bulletin* desire the best for their papers and for the publications as a whole. Careful attention to the principles presented here can go far toward achieving it. The editorial staff deeply appreciates the assistance, courtesy, and patience of its many contributors.

CORRECTIONS

GRAPHICAL CONSTRUCTION OF PERSPECTIVE DIAGRAMS

G. D. HOBSON

Bulletin, Vol. 31, No. 10 (October, 1947)

P. 1887, line 3 from bottom, should read: a, b, c, and d vertically below a, b, c, and d, respectively, . . .
P. 1888, line 4, should read: point a is obtained . . .
P. 1888, line 5, should end: equal to N′ *a*′.
P. 1891, line 7, should read: if in plan the grid a b c d is vertically below a b c d. . . .
P. 1892, Figure 5 cut line should read: Diagram assembled from two perspective grids of Figure 4.

WILCOX (EOCENE) STRATIGRAPHY, A KEY TO PRODUCTION

DOROTHY JUNG ECHOLS AND DORIS S. MALKIN

Bulletin, Vol. 32, No. 1 (January, 1948)

P. 20, Table I, Colorado County, line 1, column 4, should read: 8,256–8,316.
P. 20, Table I, footnote, last line, should read: 1939–1946.
P. 22, Table I, Live Oak County, Coquat field, line 2, column 4, should read: 7,542–48.
P. 22, Table I, San Jacinto County, Mercy field, line 1, column 4, should read: 8,209–89.
P. 23, Table I, Wilson County, Poth field, column 4, should read: 4,082–96.
P. 23, Table I, Allen Parish. So. Oberlin field, column 3, delete: 8,442?
P. 24, Table I, La Salle Parish, Olla field, line 3, column 4, should read: 2,768–75.
P. 32, References, line 21: an asterisk should precede Foster.
P. 32, References, lines 24 and 27, delete: asterisks preceding Gravell and Houston Geological Society.
P. 33, line 1, delete: asterisk.
P. 33, line 8, should read: Vol. 25.

OIL-RESERVE PROVINCES OF MIDDLE EAST AND SOUTHERN SOVIET RUSSIA

F. JULIUS FOHS

Bulletin, Vol. 31, No. 8 (August, 1947)

P. 1372, Abstract, paragraph 2, line 3, annual production of 1,600,000 barrels, should read: daily production of 1,600,000 barrels.

Line 4, production was 729,000 barrels, should read: daily production was 729,000 barrels.

Paragraph 3, last line, 1946 production was only 555,000 barrels, should read: 1946 daily production was only 575,085 barrels.

P. 1376, Fig. 2, cutlines should be added: Sketch map of Middle East adapted from Gregory's *Structure of Asia* and Dubertret's *Geologic Map of Syria and Adjacent Regions.*

DISTINGUISHED LECTURE TOUR

The Association distinguished lecture committee has announced the itinerary of A. I. LEVORSEN, dean of the School of Mineral Sciences, Stanford University. The following geological groups have been scheduled to hear Levorsen discuss "Time of Oil Accumulation" on the dates given.

March 18—Rocky Mountain Association of Geologists at Denver, Colorado
19—Colorado School of Mines at Golden
20—New Mexico Geological Society at Albuquerque
22—Tulsa Geological Society at Tulsa, Oklahoma
23—Mississippi Geological Society at Jackson
25—South Texas A.A.P.G. Section at San Antonio
26—Houston Geological Society at Houston
27—West Texas Geological Society at Midland

New officers of the Society of Economic Paleontologists and Mineralogists recently elected by mail ballot for the year beginning April 30 are: president, R. DANA RUSSELL, San Diego, California; vice-president, J. B. GARRETT, JR., Houston, Texas; secretary-treasurer, H. B. STENZEL (re-elected), Austin, Texas.

The Eastern Section of the Association has elected the following new officers for the year 1948: president, W. P. HAYNES, Standard Oil Company (New Jersey); vice-president, HOLLIS D. HEDBERG, Gulf Oil Corporation; treasurer, G. MARSHALL KAY, Columbia University; secretary, DOUGLAS A. GREIG, Standard Oil Company (New Jersey), Room 3150 at 30 Rockefeller Plaza, New York City.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 2 (FEBRUARY, 1948), PP. 312-316

AT HOME AND ABROAD

NEWS OF THE PROFESSION

PAUL D. BALBIN has been transferred from division seismograph supervisor of the Stanolind Oil and Gas Company in Fort Worth, Texas, to geophysical supervisor in the general office in Tulsa, Oklahoma.

C. E. BURBRIDGE may be addressed in care of Cia. Minera y Refinadora Mexicana, S. A., Estacion Wadley, S. L. P., Mexico.

ROBERT W. KLINE has resigned from the Sinclair Prairie Oil Company and has joined the Saltmount Oil Company at San Antonio, Texas.

New officers of the Dallas Geological Society, Dallas, Texas, for the year of 1948 are as follows: president, RAYMOND A. STEHR, Seaboard Oil Company; vice-president, JOHN T. ROUSE, Magnolia Petroleum Company; secretary-treasurer, H. V. TYGRETT, Atlantic Refining Company; executive committee member, BARNEY FISHER, Comanche Corporation.

IRA H. CRAM, assistant chief geologist for the Pure Oil Company, Chicago, has been appointed manager of exploration. Cram has been with the Pure 23 years.

P. E. FITZGERALD, who has been associated with Dowell for 15 years, continues as the company's geologist and membership on the board of United Oilwell Service, and has the new responsibility of managing the foreign sales and export department of Dowell Incorporated at the company's general offices at Tulsa, Oklahoma.

CLIFFORD N. HOLMES has received the Master's degree in geology at Yale University and has returned to the United States Geological Survey, Washington, D. C.

The following papers was recently presented before the Oklahoma City Geological Society: L. B. TROMBLA, Central Exploration Company, November 11, "Seismograph Exploration as a Tool to a Geologist"; J. G. BARTRAM, Stanolind Oil and Gas Company, December 2, "The Jurassic of Colorado"; ERWIN L. SELK, Stanolind Oil and Gas Company, "Problems of the 'Mayes' in Oklahoma."

J. F. JUDSON, formerly with the United Geophysical Company, is a party chief with the Seismograph Service Corporation, at Caracas, Venezuela.

DONALD I. GAHAGAN has left the Skelly Oil Company. He is with the Pan American Production Company at Houston, Texas.

H. A. KOCH, of Dowell, Inc., talked on "Practical Applications of the Electric Pilot in Permeability Surveys and Acidizing" at the meeting of the Tulsa Geological Society, January 5.

Old-time friends of the late poet-geologist, CLYDE M. BECKER, of Chickasha, Oklahoma, recently had memories kindled and hearts warmed anew upon reading again *The Ramblin' Rock Hound* which has been republished in new format by C. J. PETERSON of Amarillo, Texas. Each of the six episodes is illustrated by an eloquent black-line drawing done by H. H. HUTSON.

F. D. BODE, of The Texas Company, spoke on "Observations on the Geology of Sicily," at the meeting of the Geological Forum of the Pacific Section of the Association, at Pasadena, California, December 15, 1947.

LAURENCE BRUNDALL, vice-president of Geophoto Services, Denver, recently presented an illustrated talk before the Pittsburgh Geological Society on "Photogeology and Its Applications to Petroleum Exploration."

CARL A. MOORE, associate professor of geology, University of Oklahoma, spoke before the Society of Sigma Xi, December 18, on "The Morrow Series of Rocks in Northeastern Oklahoma." This complete work has recently been published as *Bulletin 66* of the Oklahoma Geological Survey, Norman.

RALPH W. MELHORN, consulting geologist of Owosso, Michigan, died on April 23, 1947. During the war he was with the Petroleum Administration for War in Chicago and Washington, D. C.

The University of Louvain, Louvain, Belgium, on October 20, 1947, awarded W. H. TWENHOFEL the honorary degree of Doctor of Science because of his contributions to sedimentary geology.

VINCENT W. VANDIVER has recently returned to Los Angeles from a month's trip to Venezuela where the Seaboard Oil Company has a joint operation with the Creole Petroleum Corporation in the Pedernoles area.

The Pacific Section of the Association held its first luncheon meeting of the new year on January 8 at the Clark Hotel, Los Angeles. EARL B. NOBLE, manager of exploration for the Union Oil Company, spoke on "Oil Exploration in Northern Alaska." He recently returned from a trip to Alaska.

The San Joaquin Geological Society (Bakersfield, California) officers for the current year are: president, EUGENE H. VALLAT, Ohio Oil Company; vice-president, JOHN H. BEACH, Independent Exploration Company; secretary-treasurer, ROBERT RIST, Standard Oil Company of California.

R. C. MILLS, JR., formerly of Houston, Texas, can now be addressed at 411 Medical Professional Building, Corpus Christi, Texas, where he has recently opened an office for the Standard Oil Company of Texas.

J. R. LOCKETT, 378 Sherbourne Drive, Columbus, Ohio, desires to bring to the attention of the members his willingness to furnish the name and address of a geologist in Great Britain, on an order form to CARE in New York, to anyone interested in sending a package of food or other commodities to someone in that country who would appreciate such assistance. Anyone interested may send his name and address to Lockett.

JOE A. LAIRD has resigned his position as petroleum engineer and geologist for George W. Strake, Houston independent oil operator, and is now in independent and consulting work in Houston, Texas.

S. T. WAITE has been transferred to Egypt as chief geologist for the Anglo-Egyptian Oilfields, Ltd., Shell House, Box 228, Cairo.

STANLEY W. WILCOX, of the Seismograph Service Corporation, is situated in Caracas, Venezuela, Apartado 1488.

H. M. HARSVELDT is with the Standard Vacuum Petroleum Mattschappy, Soengei-Gerong, Nederlandsch Oost. Indie.

PAUL H. KOLM has changed his address from the Forest Oil Company to the Permian Basin Sample Laboratory, Midland, Texas.

JOHN T. LONSDALE spoke on the "Geology of the Big Bend Region of Texas," at the meeting of the Houston Geological Society, January 12.

FRANK A. HERALD, of Austin, joined the staff of the University of Texas Bureau of Economic Geology, January 1. He will act as editor and supervisor of the Oil Fields and Texas project.

H. B. STENZEL, for many years with the Bureau of Economic Geology at Austin, has, in addition, been appointed graduate professor of geology in the University of Texas department of geology.

The Geological Forum of the Pacific Section of the Association met at Occidental College, January 19, under the chairmanship of W. T. ROTHWELL, JR., Richfield Oil Corporation. "Australia in Color," was shown by PAUL H. DUDLEY, district geologist, Richfield Oil Corporation. JAMES GILLULY, professor of geology, University of California at Los Angeles, recently elected president of the Geological Society of America, discussed "Geological Society of America Activities."

New officers of the Fort Worth Geological Society, Fort Worth, Texas, are: president, R. H. SCHWEERS, The Texas Company; vice-president, F. H. SCHOUTEN, Stanolind Oil and Gas Company; secretary-treasurer, MILLICENT A. RENFRO, Texas Pacific Coal and Oil Company.

A. K. TYSON has resigned the managership of the land department of the southern division of the Continental Oil Company, Houston, Texas, to become vice-president of the Barber Asphalt Company, 2221 Commerce Building, Houston.

ELMER FRED DAVIS, of Los Angeles, California, chief consulting geologist for the Shell Oil Company, Inc. in North America, has retired after 30 years of service. He has been vice-president of the company since 1940.

SHERMAN A. WENGERD, associate professor of geology at the University of New Mexico, Albuquerque, gave a lecture on "Exploration in the Canadian Arctic" before the Geology Club at the University, in November. In January, he lectured on "Geological Investigations on the Arctic Slope, Alaska," before the Society of Sigma Xi and the Geology Club.

E. O. BUCK, who has been southern manager for the Rowan Drilling Company since 1943, is associated with the National Bank of Commerce, Houston, Texas, as manager of its oil loan department.

R. H. SHERMAN has resigned as a vice-president of the Creole Petroleum Corporation to accept a position with the Standard Oil Company (New Jersey) as assistant coordinator of producing activities. He continues as a director of Creole.

A. FREIE, formerly production manager of the Creole Petroleum Corporation in Caracas, Venezuela, will assume the duties formerly assigned to R. H. SHERMAN as head of the producing section of Creole's New York office. Freie has been associated with Jersey Standard interests since 1929 and has spent the last 17 years in Venezuela in geological and producing activities.

GRADUATE ASSISTANTSHIPS

Graduate Assistantships paying from $900 for an academic year and $1200 for a calendar year, are available in the department of geology and geography of Rutgers University, New Brunswick, New Jersey. Holders of these positions have free tuition. Graduate assistants will serve half-time in laboratories, grading papers, *et cetera*. Two years are normally spent in meeting the requirements for the Master's degree.

Scholarships without stipend are also available for selected students. These scholarships carry remission of fees and the student has full time for research and study. One year's residence fulfills the requirement for the Master's degree.

Before the applicant can qualify for either the Graduate Assistantships or the Scholarships without stipend, forms for admission to the Graduate School should be obtained and returned to the Executive Secretary of the Graduate Faculty of Rutgers University.

Applicants who have had training in geology, geology with a geographic background, or geography with a geologic background may write to the chairman of the department of geology and geography for the assistantships and to the executive secretary for scholarships without stipend before September 15, of the current year.

Proof of admission to the Graduate School of Rutgers University must be submitted with each application.

WILLIAM B. WATSON is associated with DAVID DONOGHUE, consulting geologist and engineer, of Forth Worth, Texas. Watson, formerly in the production and engineering departments of the Gulf Oil Corporation and captain in the United States Marine Corps in the Pacific during World War II, is now completing requirements for the degree of Master of Science in petroleum engineering at the University of Texas.

HALL TAYLOR returned from Africa in January and resumed teaching in the department of geology, Columbia University, New York City. During his 6 months' leave of absence from Columbia University he made stratigraphic studies for the Sinclair Petroleum Company, working first in Italy and later in Ethiopia.

The Panhandle Geological Society of Amarillo, Texas, recently elected new officers for 1948: president, CARLOS M. FERGUSON, Magnolia Petroleum Company; vice-president, ROBERT J. GUTRU, Cities Service Oil Company; secretary-treasurer, FREDERICK S. ALEXANDER, Standard Oil Company of Texas.

L. MURRAY NEUMANN, consulting geologist of the Carter Oil Company, Tulsa, Oklahoma, has retired from active duty after 32 years of service in geological exploration for that company. He was employed by the Carter in 1916 as one of its first geologists. In 1918 he became chief geologist and in 1934 consulting geologist of the organization. His home address is 32 East 26th Place, Tulsa.

WILLIAM G. BLACKWELL has given up his consulting practice in Baton Rouge, Louisiana, to become engineer-in-charge of drilling in Mexico for J. Edward Jones of New York, N. Y.

MERLE C. ISRAELSKY has left the Sohio Petroleum Company, Houston, Texas, to enter the employ of the United States Geological Survey. He may be addressed in care of A. O. WOODFORD, Pomona College, Claremont, California. On January 21, Israelsky talked before the Houston Geological Society on "An Oscillation Chart, a Possible Correlative Tool," as illustrated by a well in the Lireet field, Louisiana.

LUTHER E. KENNEDY, formerly president of the Peters Petroleum Corporation, is now engaged in independent consulting practice. His address is 1735 Victor Avenue, Tulsa, Oklahoma.

CARROLL M. WAGNER, manager of the geological department of the General Petroleum Corporation, Los Angeles, California, has been chosen a director of the corporation.

JOSEPH ZABA, of Houston, Texas, has been appointed chief mechanical engineering supervisor of the Stanolind Oil and Gas Company with headquarters in Tulsa.

RALPH H. FASH, consulting chemist, announces that he has sold his interests in the Fort Worth Laboratories, the Southwestern Laboratories, and the Houston Laboratories, and has opened an office as consultant on chemical problems, at 1811 W. T. Waggoner Building, Fort Worth 2, Texas.

S. R. NORMAND has left the Independent Exploration Company and is now with Cummins, Berger, and Pishny in Fort Worth, Texas.

The Division of the Geological Sciences, California Institute of Technology, announces the appointment of R. DANA RUSSELL as visiting professor, and of C. HEWITT DIX as associate professor, effective January 1, 1948.

RICHARD J. ANDERSON, economic geologist, has been appointed to the staff of Battelle Institute, Columbus, Ohio, where he will be engaged in studies on the economics of raw materials. Anderson was formerly a geologist for the Alcoa Mining Company, New York City, and more recently managing engineer with Raw Materials Survey, Inc., Portland, Oregon.

L. W. BLAU, of the Humble Oil and Refining Company, Houston, is the newly elected president of the Texas Academy of Science.

RICHARD JOEL RUSSELL, of the Louisiana State University, Baton Rouge, is president of the Association of American Geographers. He was elected at the 44th annual meeting, which was held at Charlottesville, Virginia, December 29–31.

The following new officers of the South Louisiana Geological Society, Lake Charles, Louisiana, were recently elected: president, D. E. NEWLAND, Magnolia Petroleum Company; vice-president, E. M. ROSS, JR., Amerada Petroleum Corporation; secretary, H. L. Tipsword, Magnolia Petroleum Company; treasurer, PHILIP R. ALLIN, Gulf Oil Corporation. Other members of the executive committee are: W. R. CANADA, Magnolia Petroleum Company, and W. D. SMITH, Union Sulphur Company.

The Pacific Section of the Association held a luncheon meeting, February 5, at the Clark Hotel, Los Angeles. IRVING SMITH, City attorney for Long Beach, spoke on "Tidelands as Affected by the Recent U. S. Supreme Court Decision."

A. TEN DAM, formerly micropaleontologist of the Netherlands State Geological Survey at Haarlem, is now employed by the Société Nationale de Recherche et d'Exploitation des Pétroles en Algérie as chief paleontologist with his laboratory at Relizane (Algeria).

E. M. REED has been elected vice-president of the First National Bank, Houston, Texas.

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Meetings will be announced.

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Vice-President - - - - - - Don W. Payne
Sinclair Prairie Oil Company
Secretary-Treasurer - - - Alice M. Quesenbery
Cities Service Oil Company

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka. Visiting geologists and friends welcome.

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- - - - - - - - - - Joe B. Hudson
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Secretary-Treasurer - - - - D. N. Rockwood
Union Producing Company, Box 1628

Meets the first Monday of every month, October-May, inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

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Gulf Oil Corporation

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

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Superior Oil Company
Tower Building

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

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Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

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Ohio Oil Company, Thompson Building
Editor - - - - - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

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Meetings held each month, except during the summer. All meetings and other activities by special announcement.

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Box 1939

Meetings: 2d Thursday of each month, 7:00 P.M., Wooten Hotel.

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Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

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Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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Shell Oil Company, Inc., Box 2010, Radio Bldg.

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Y.W.C.A. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

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Secretary-Treasurer - - - - Fred S. Alexander
Standard Oil Company of Texas, Box 2087

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

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Secretary - - - - - - - - - Clyde W. Turner
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Permian Basin Sample Laboratory, Box 1653

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Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Daniel Boone Hotel.

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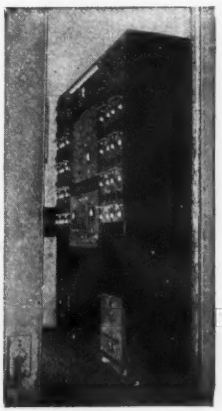

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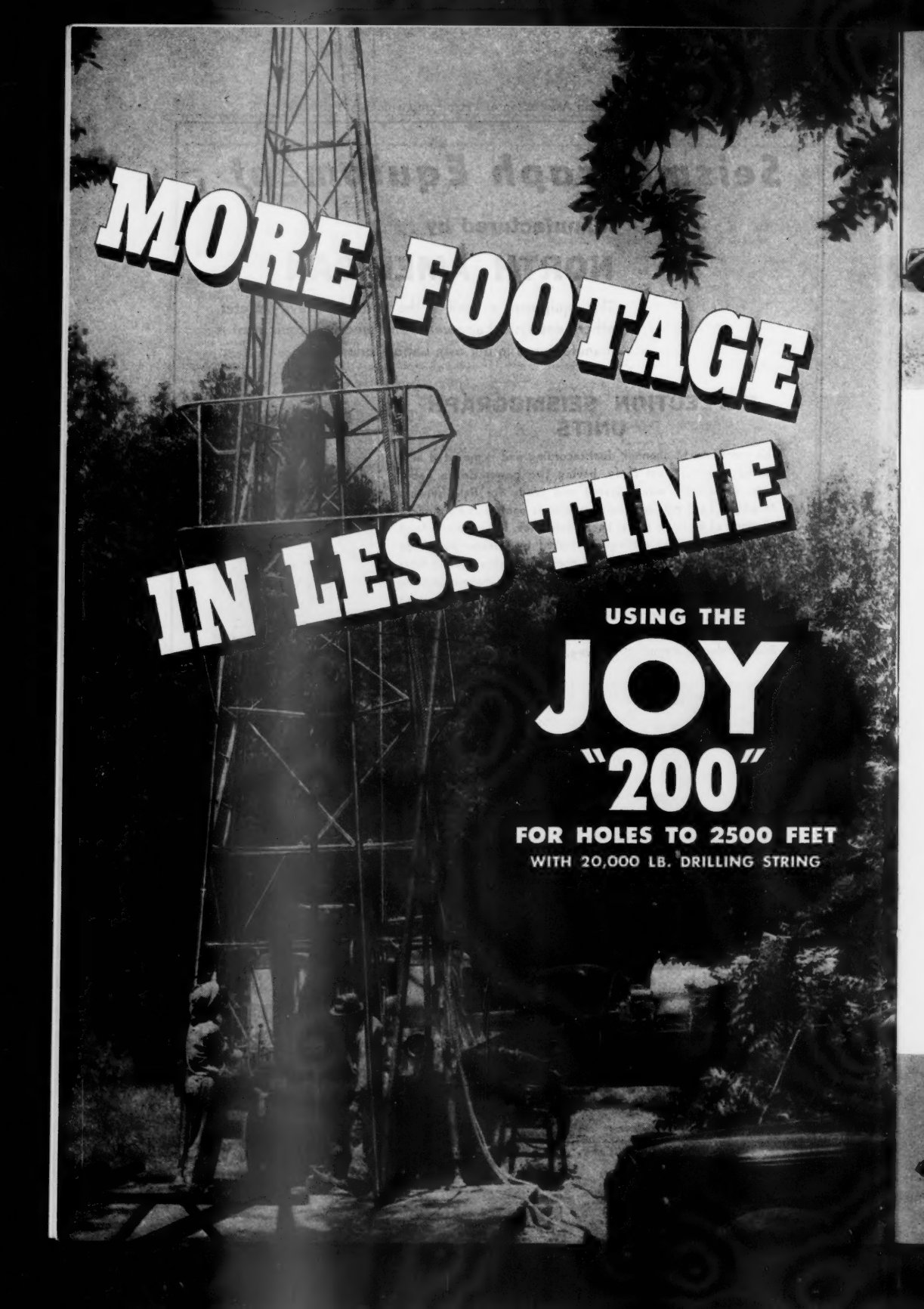
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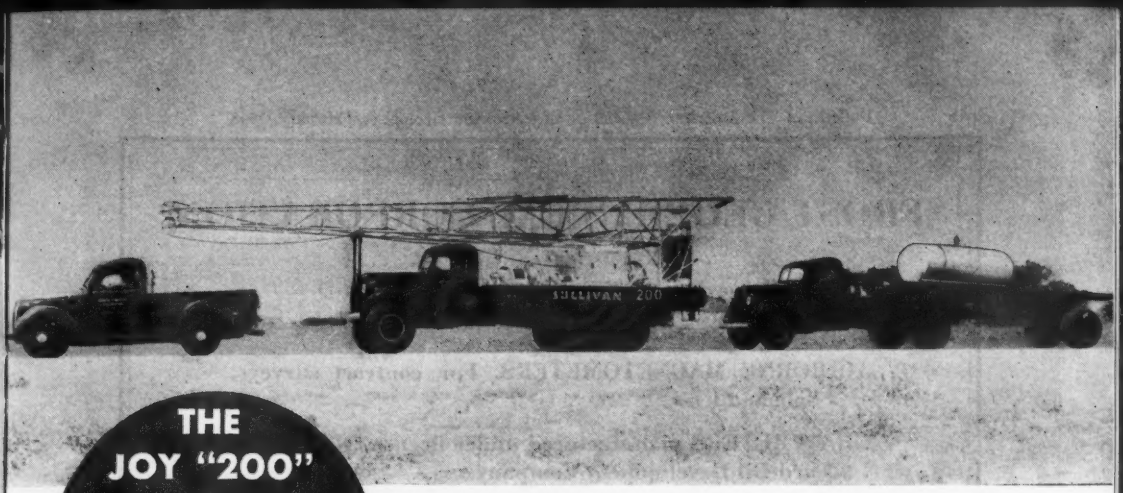

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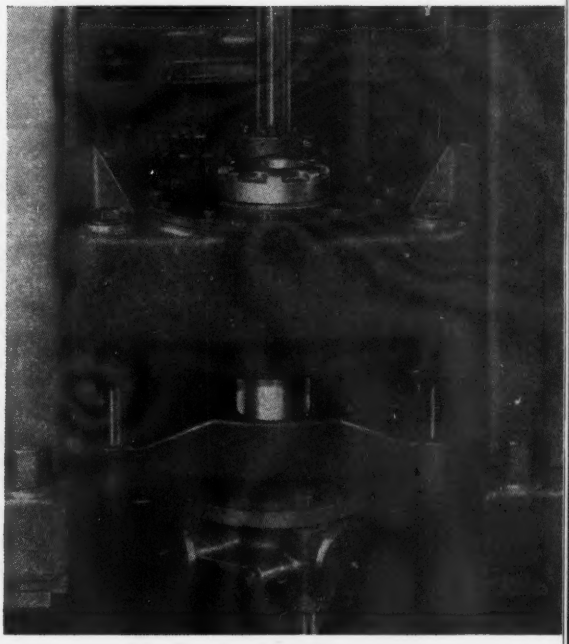

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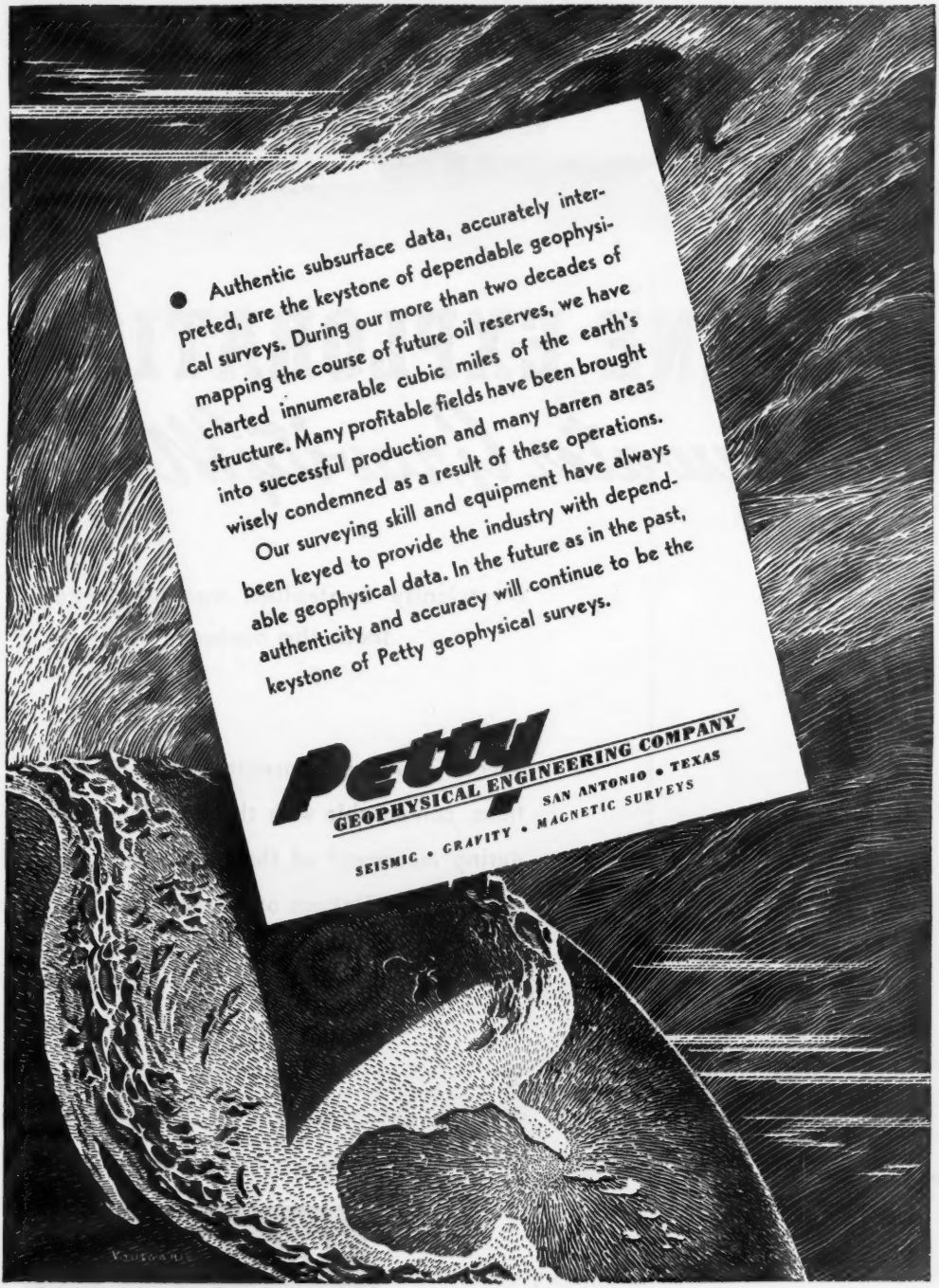
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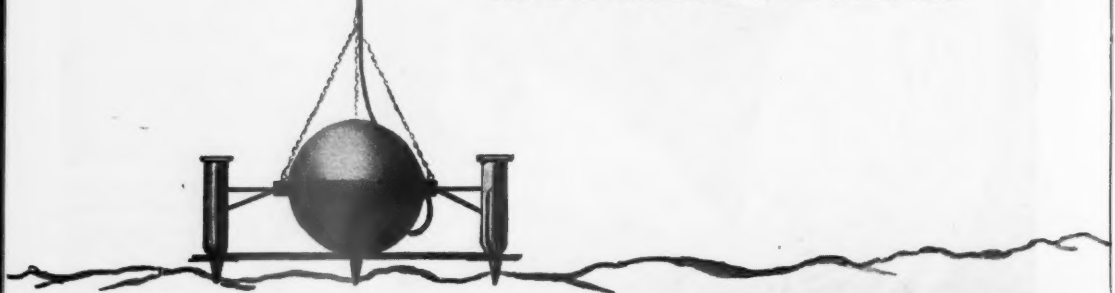

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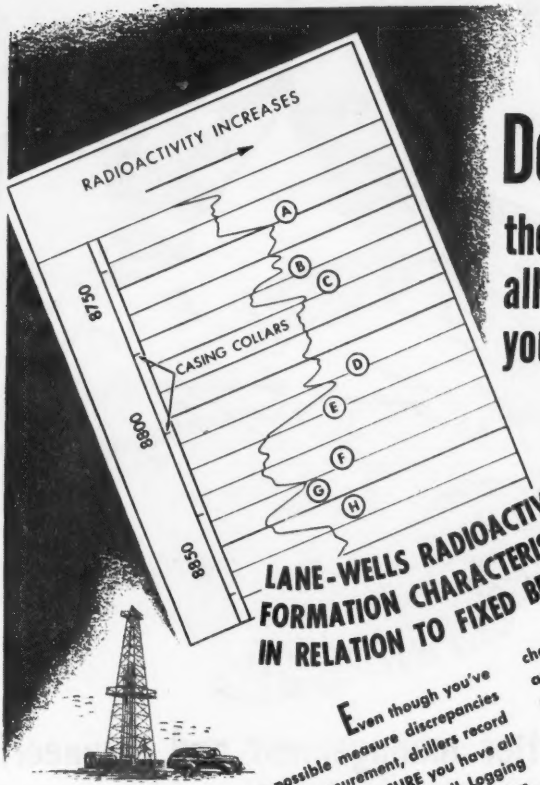

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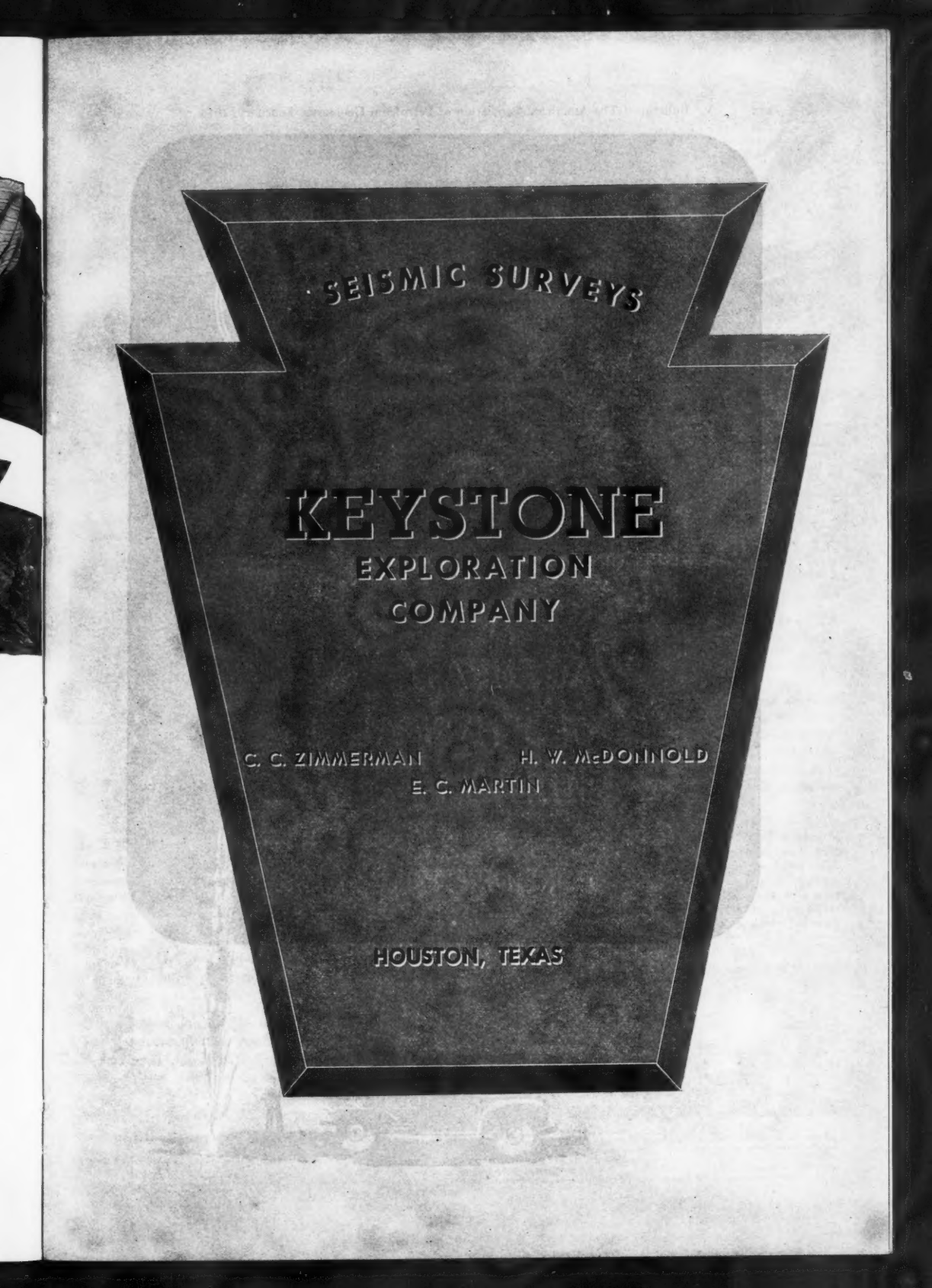
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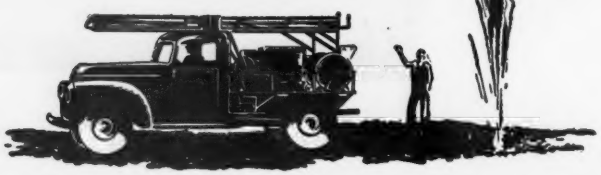

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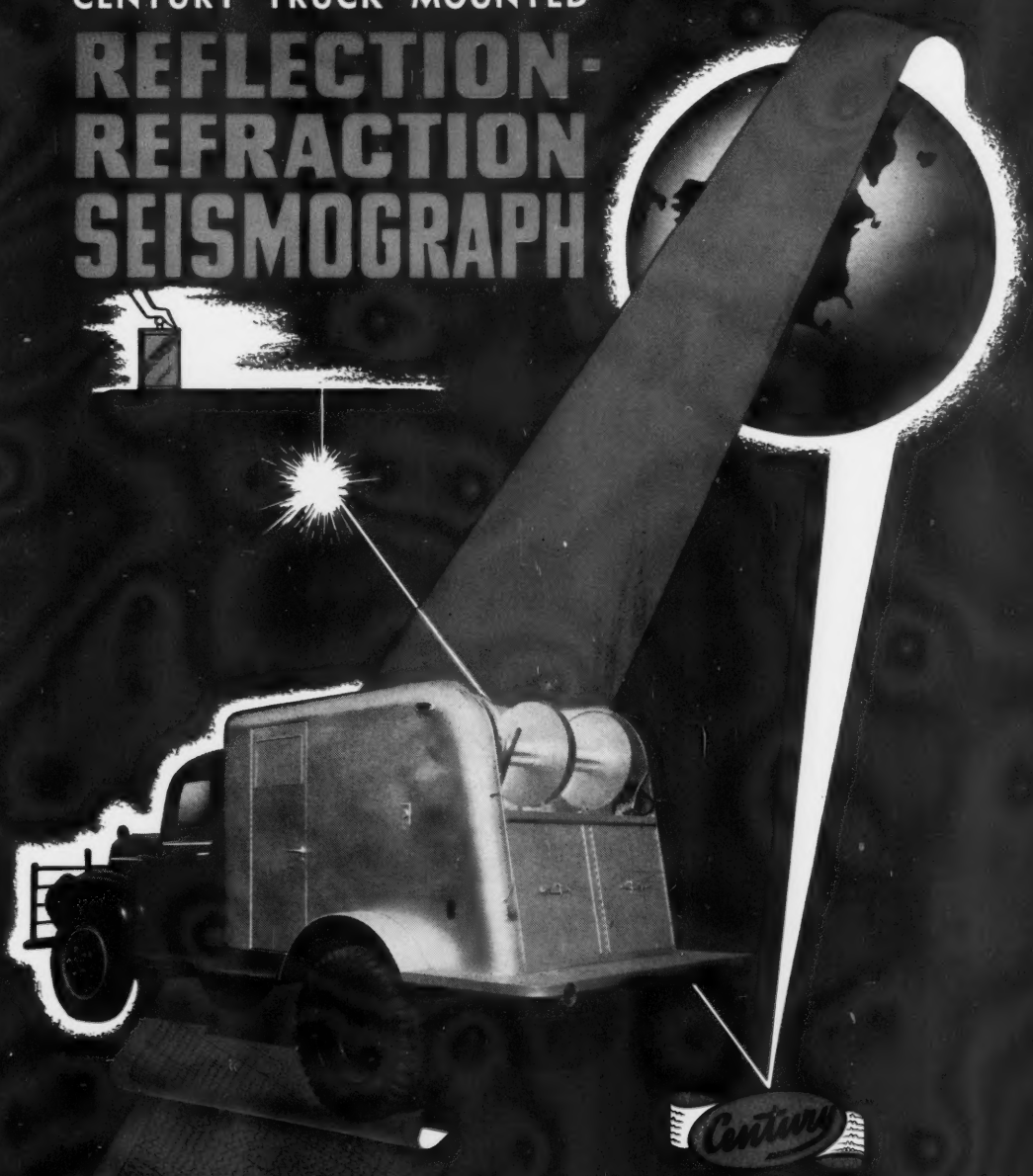

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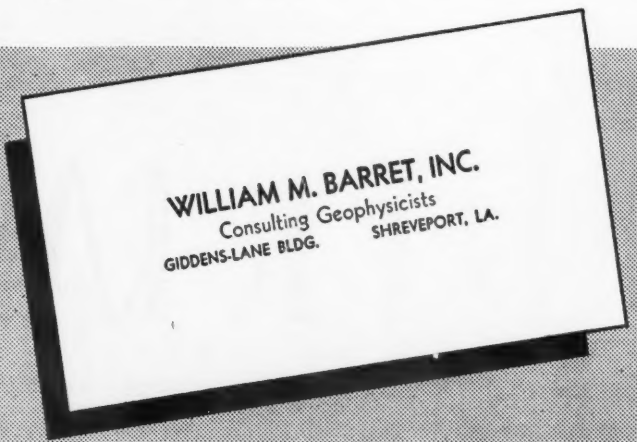

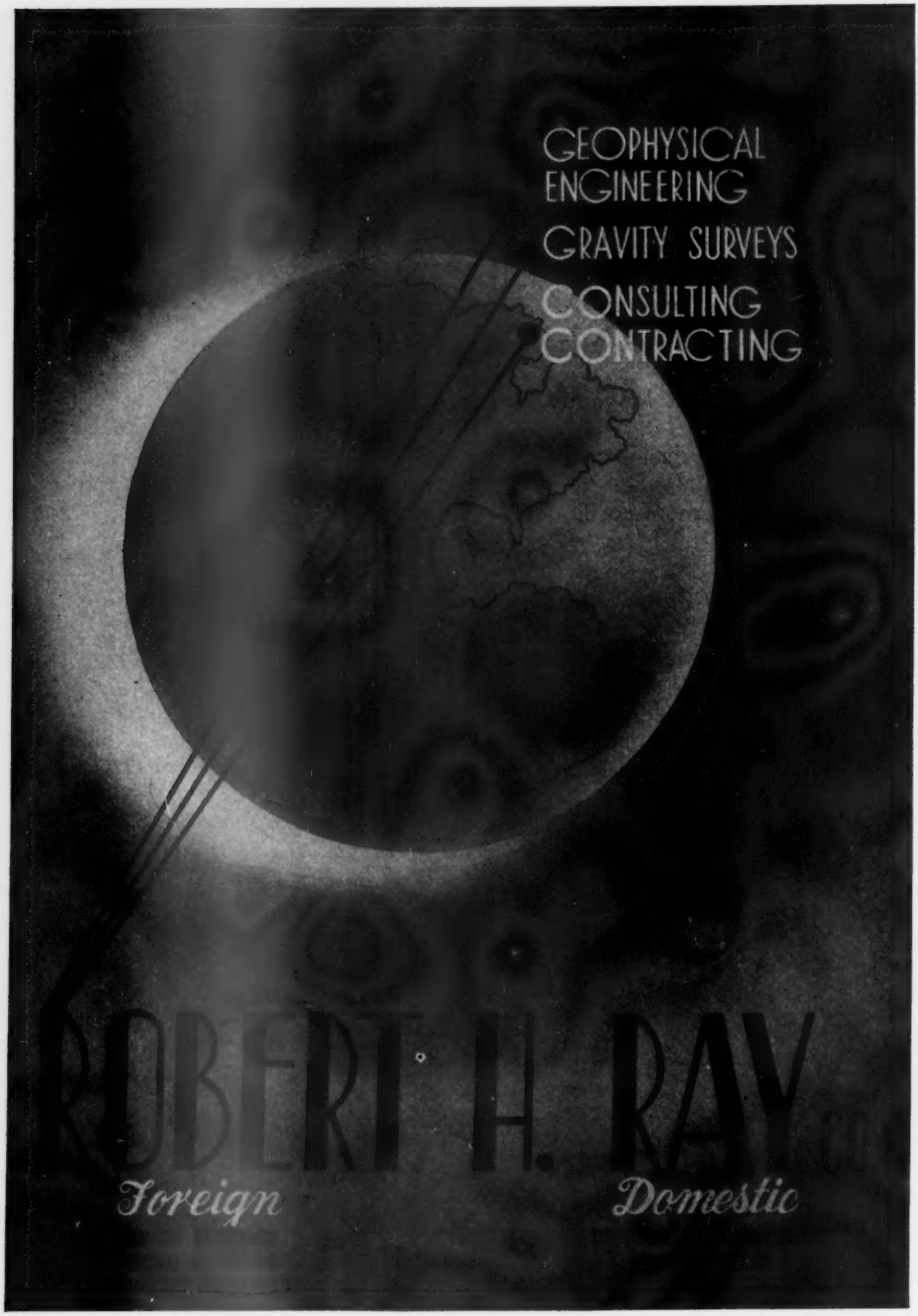
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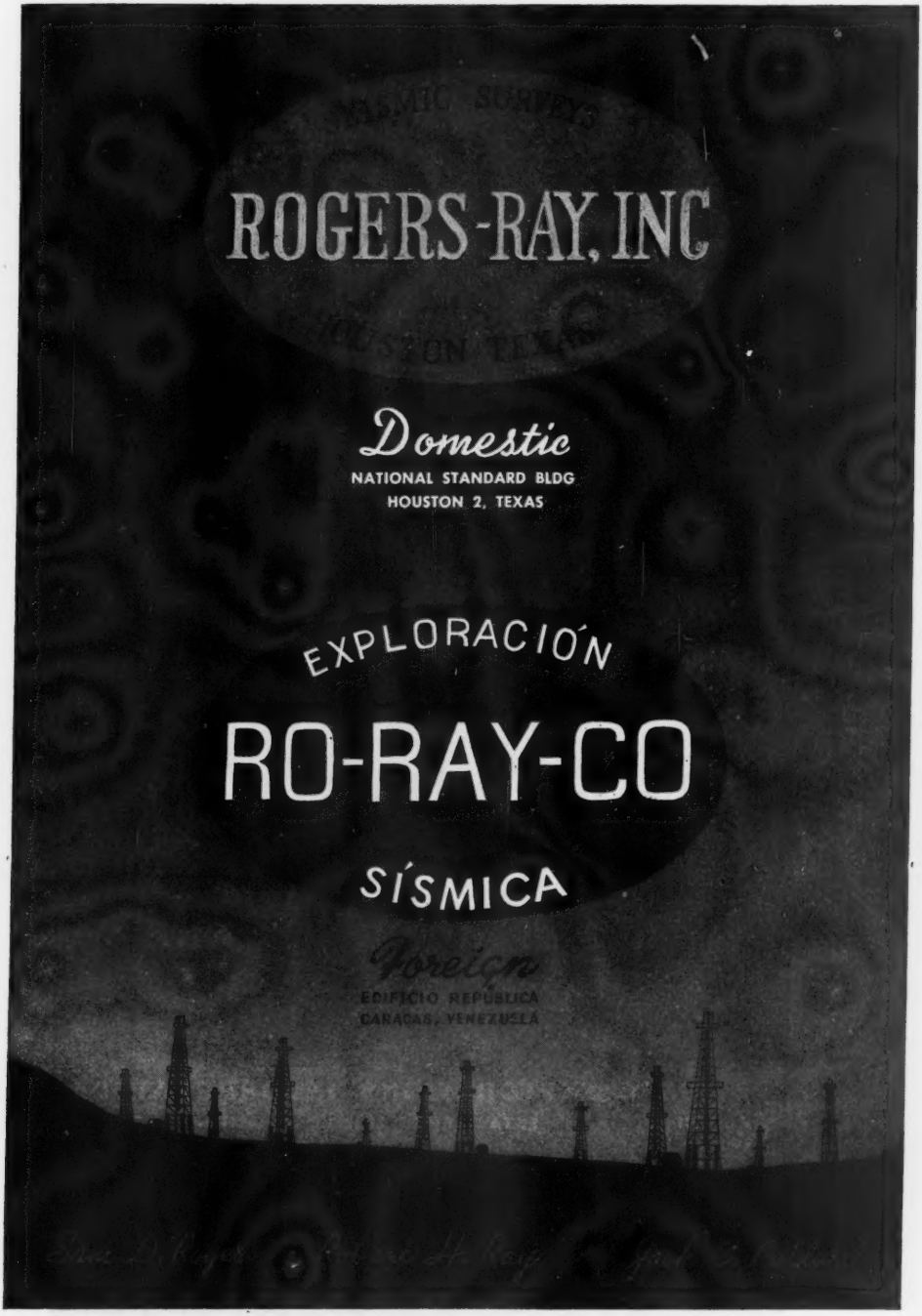
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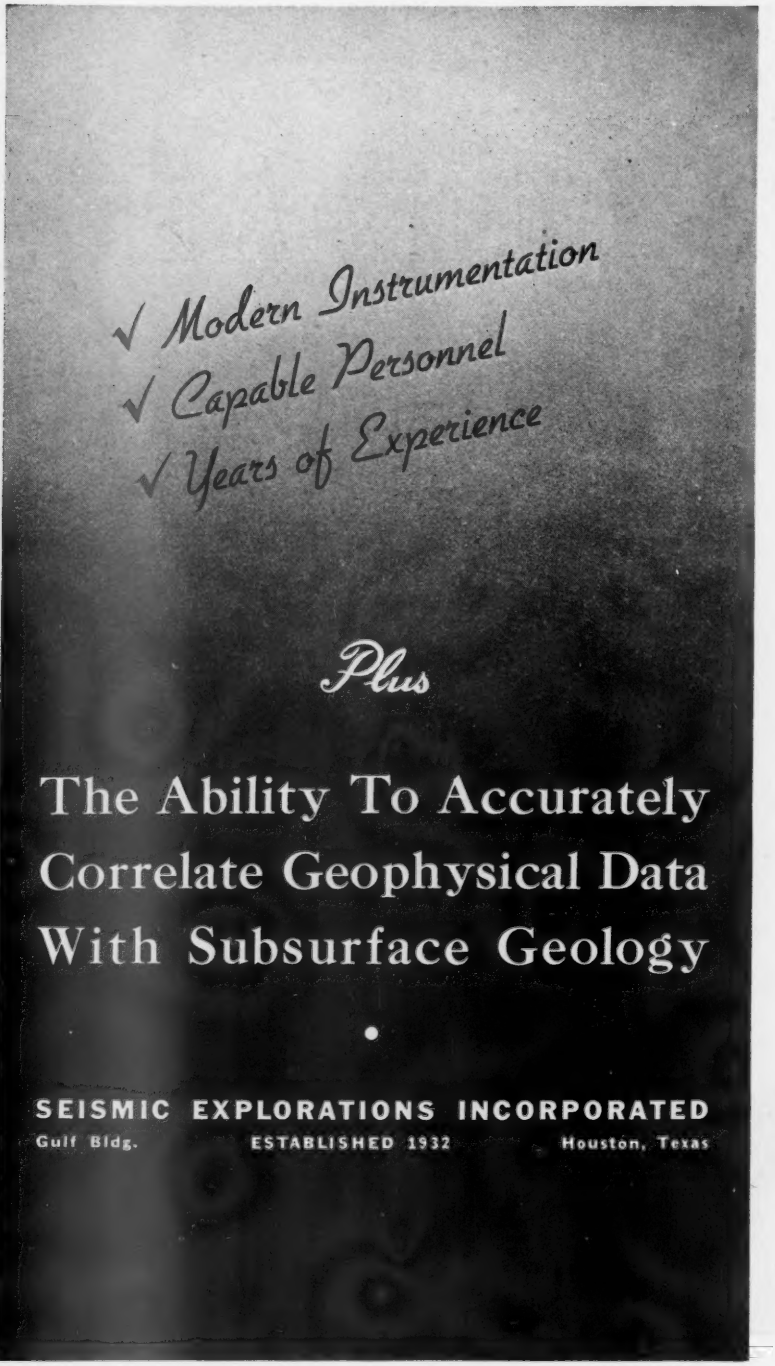
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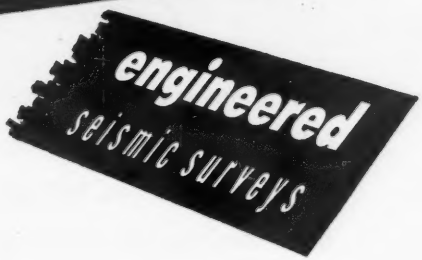

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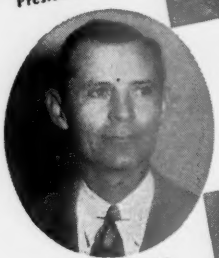

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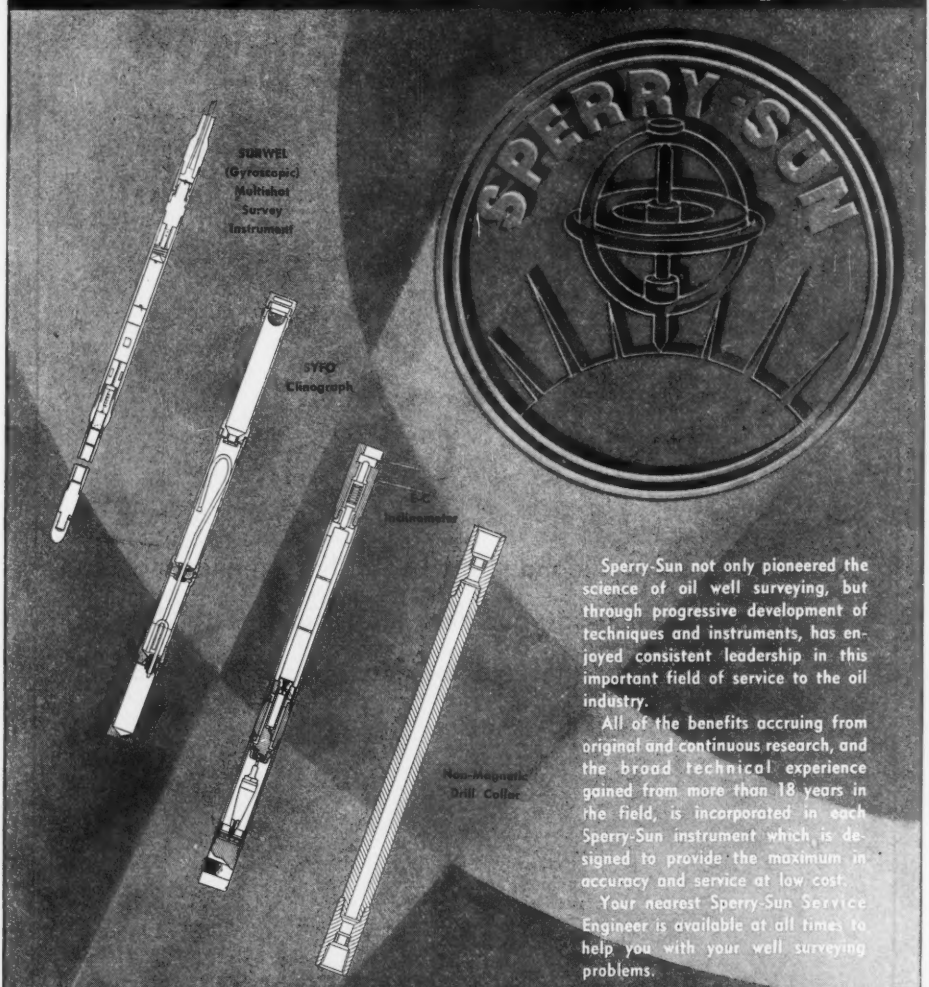

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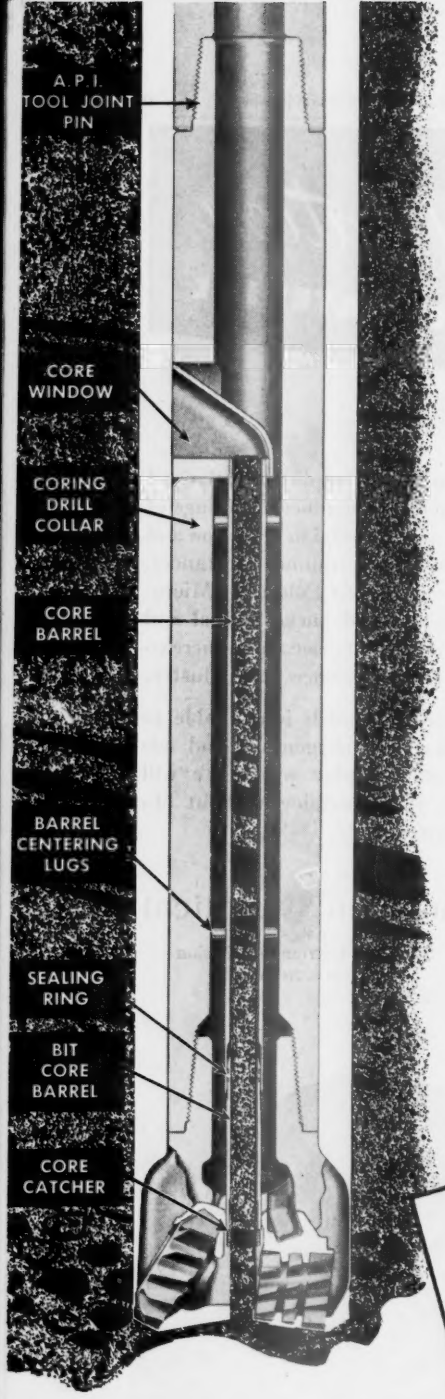

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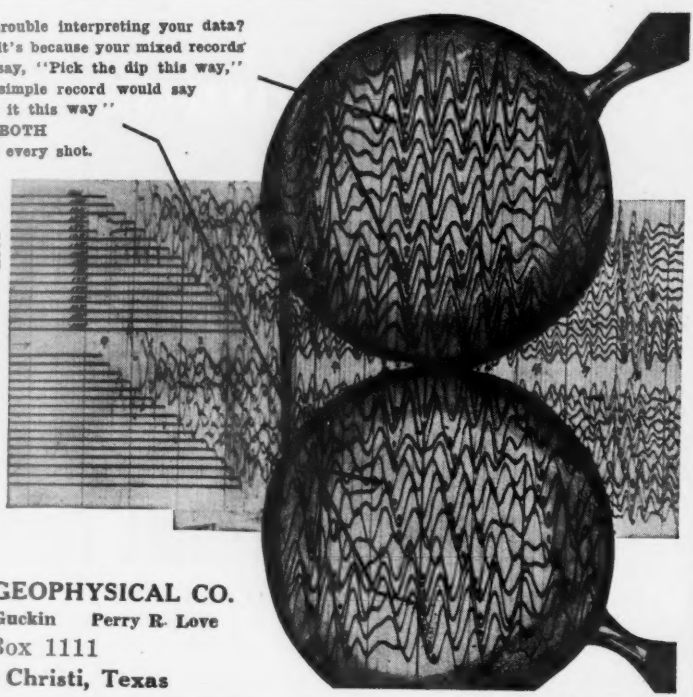

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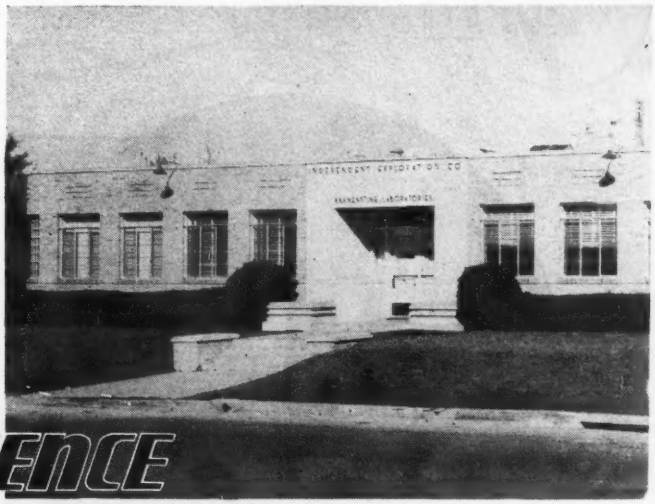

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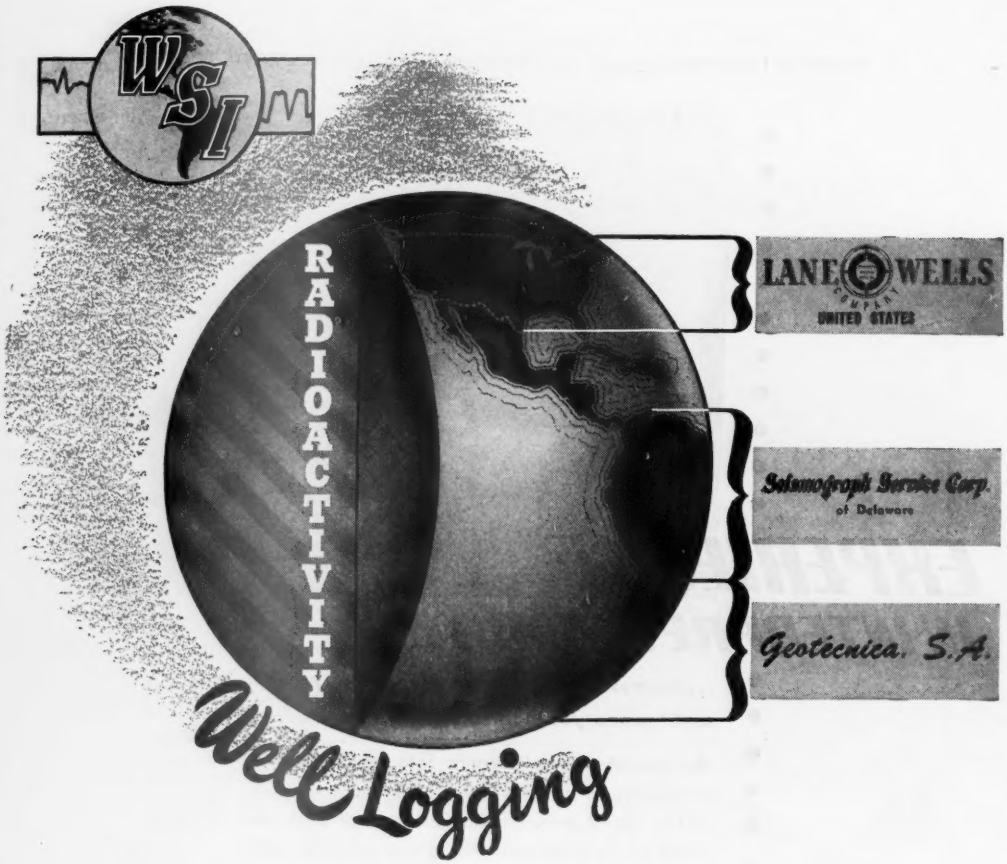

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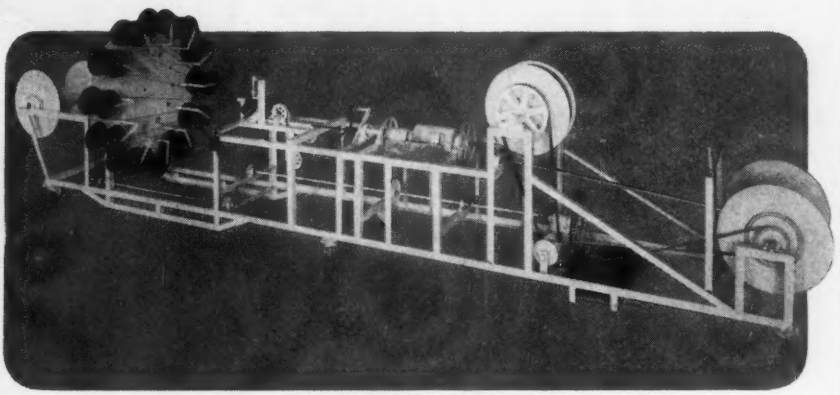

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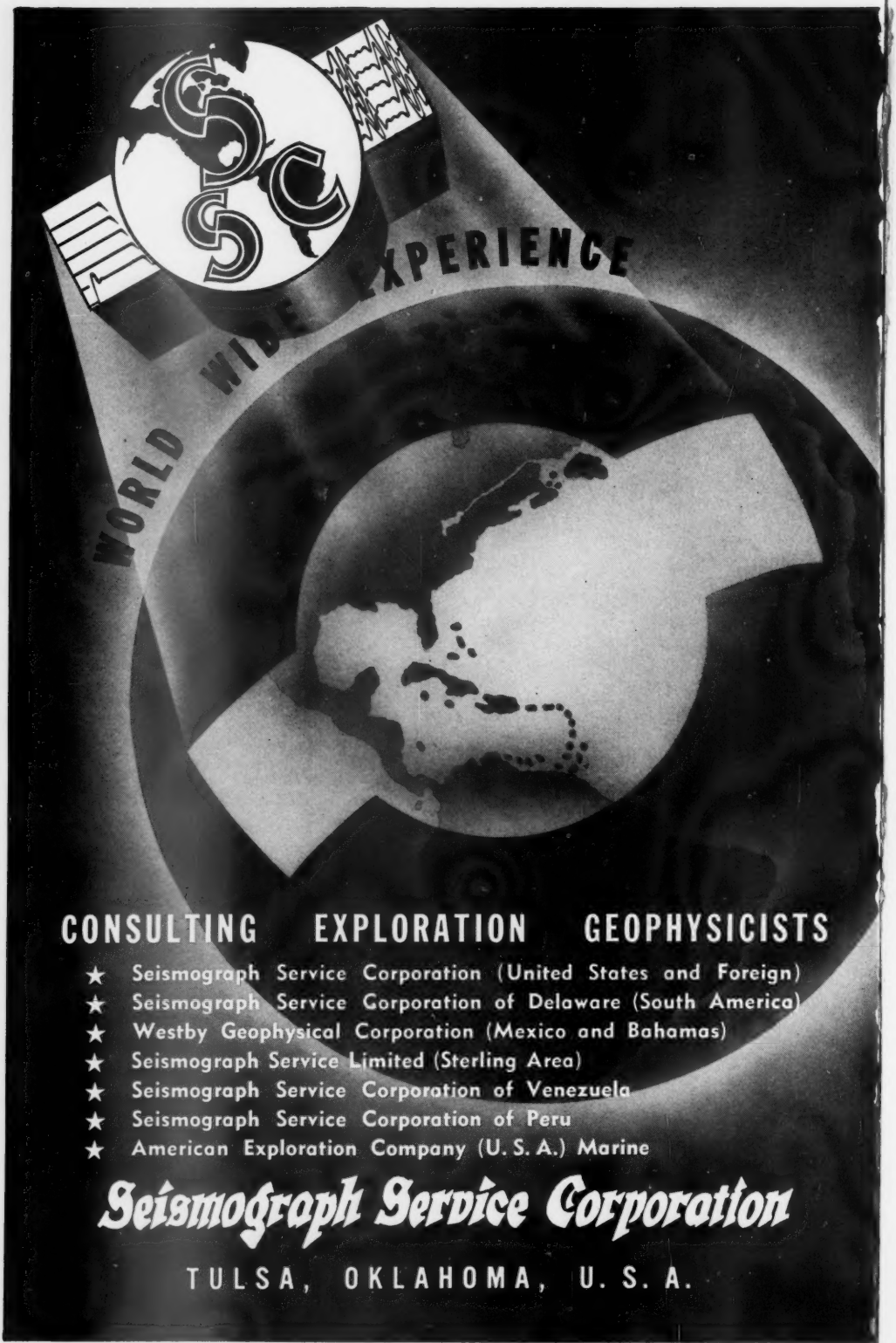

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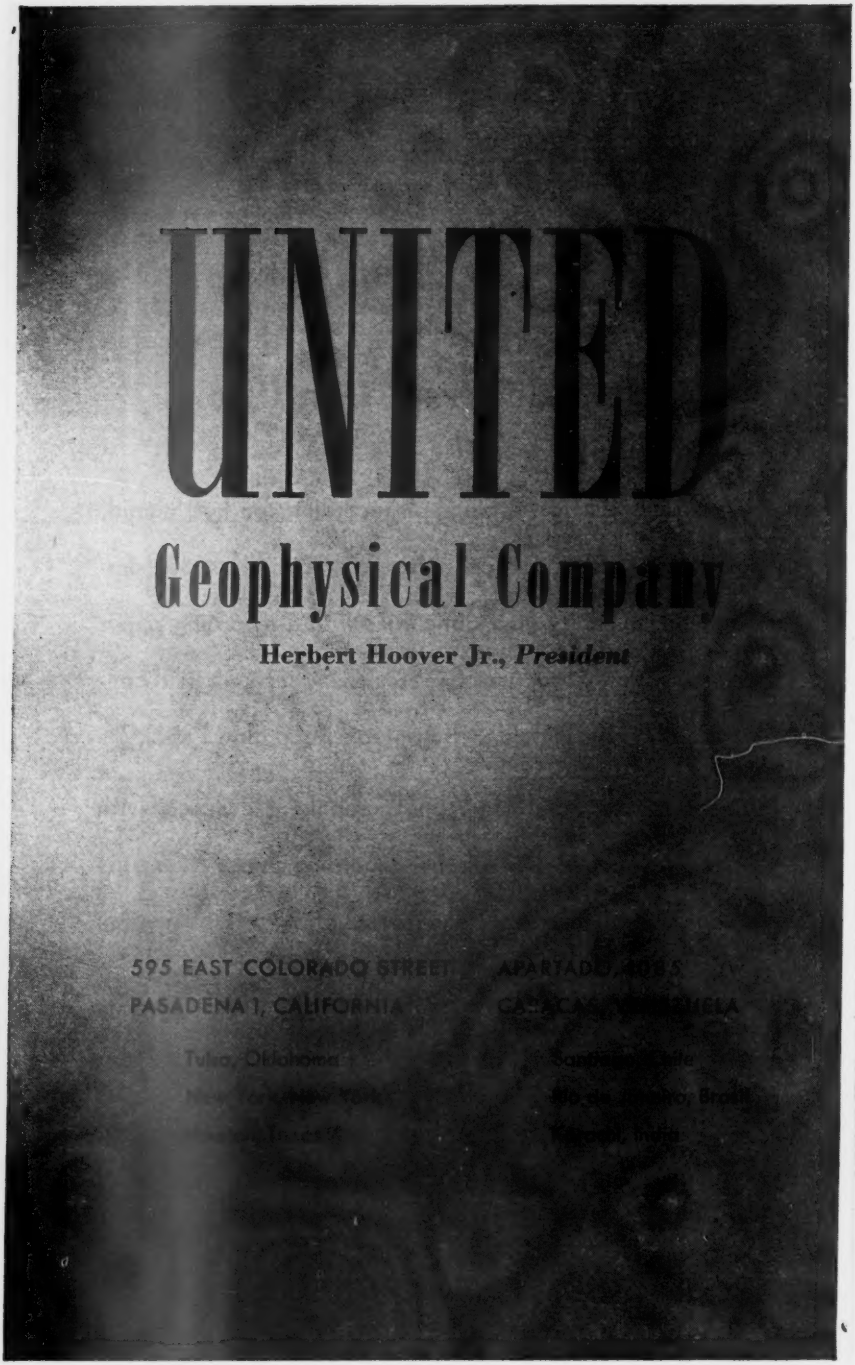
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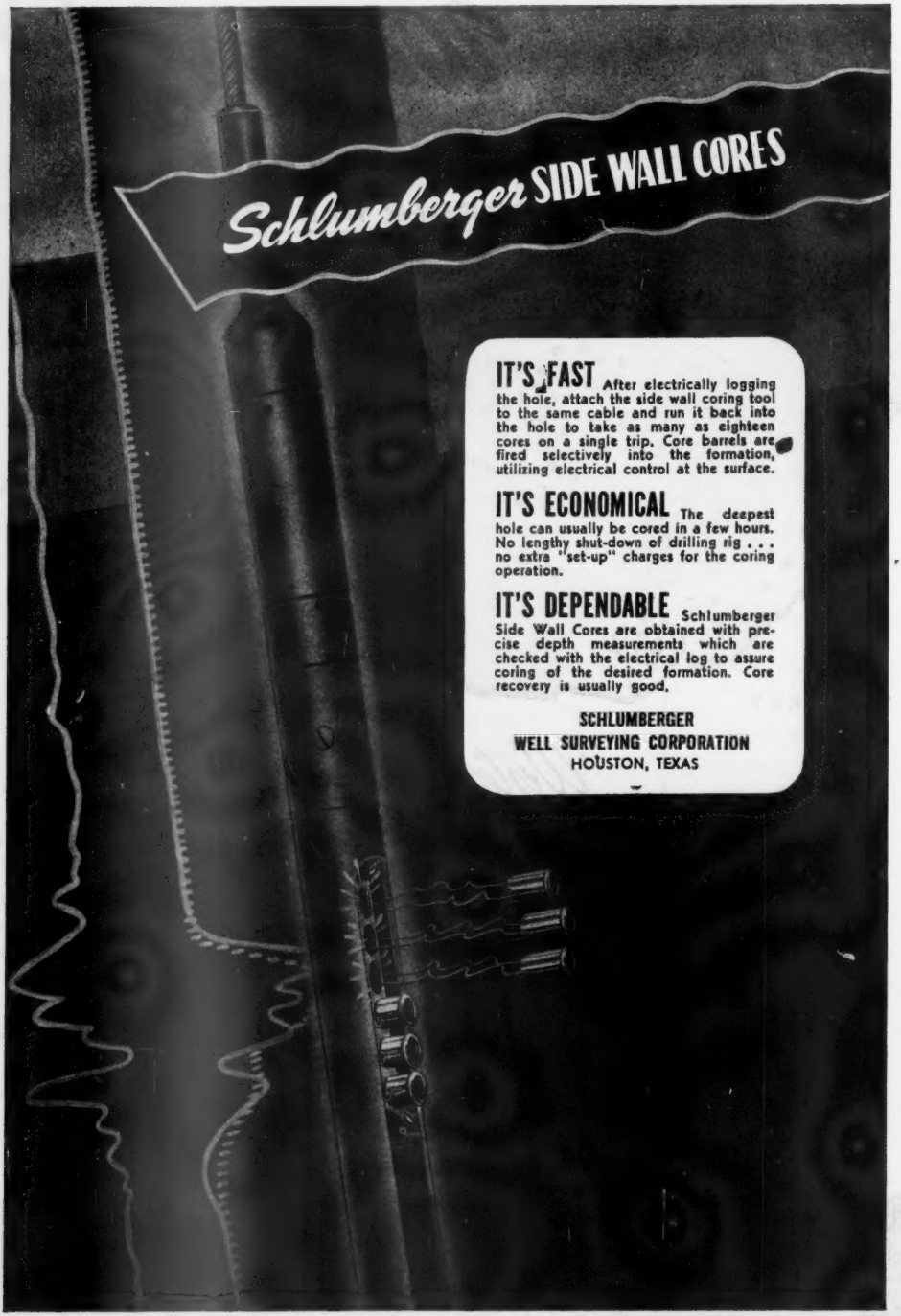
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BY STAFF OF CARIBBEAN PETROLEUM COMPANY

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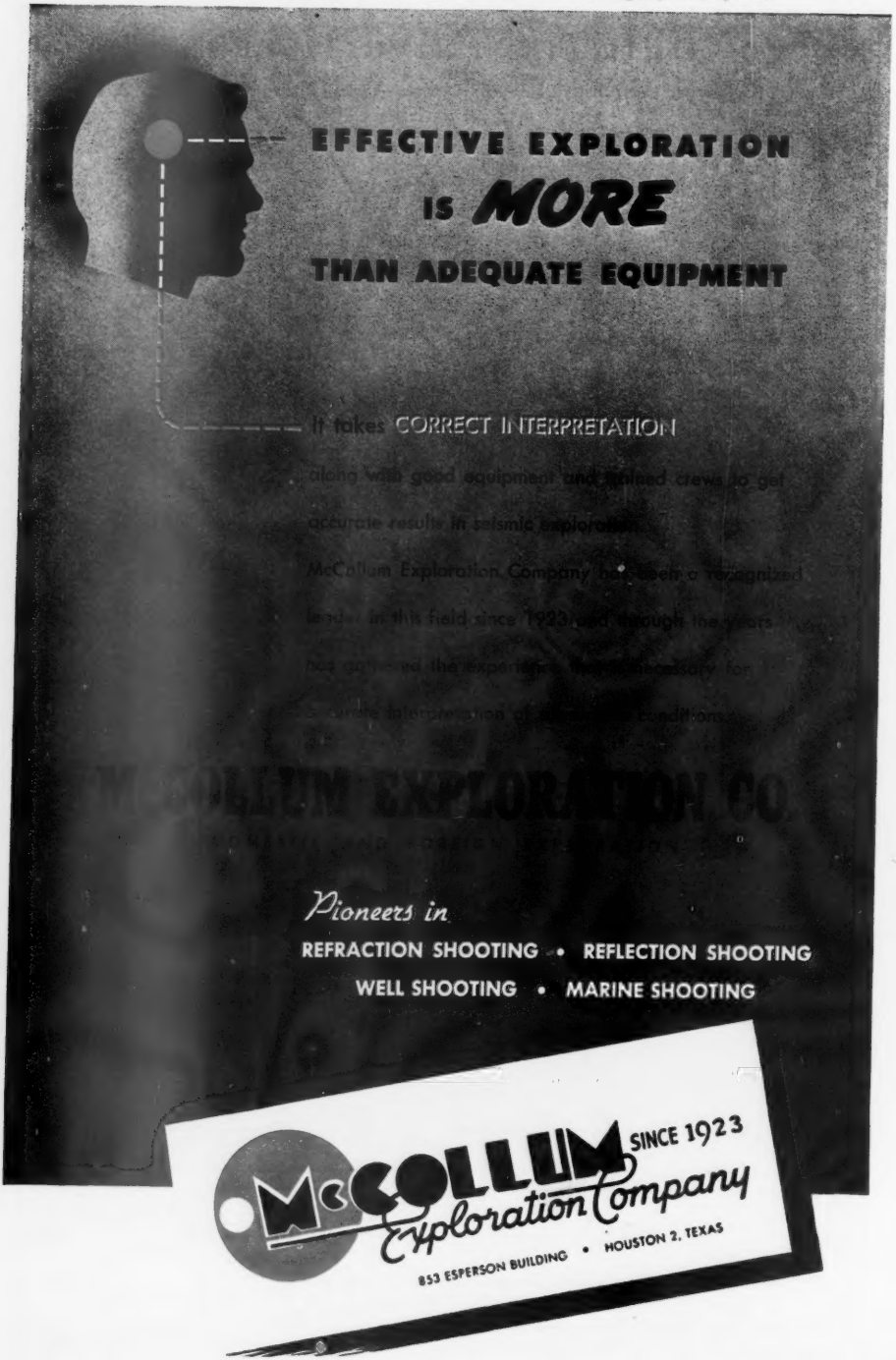
BY V. BROWN MONNETT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